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NORTH CASCADES AND OLYMPIC Science Partnership

Geology and Everyday Thinking

WESTERN WASHINGTON UNIVERSITY

SCED 202

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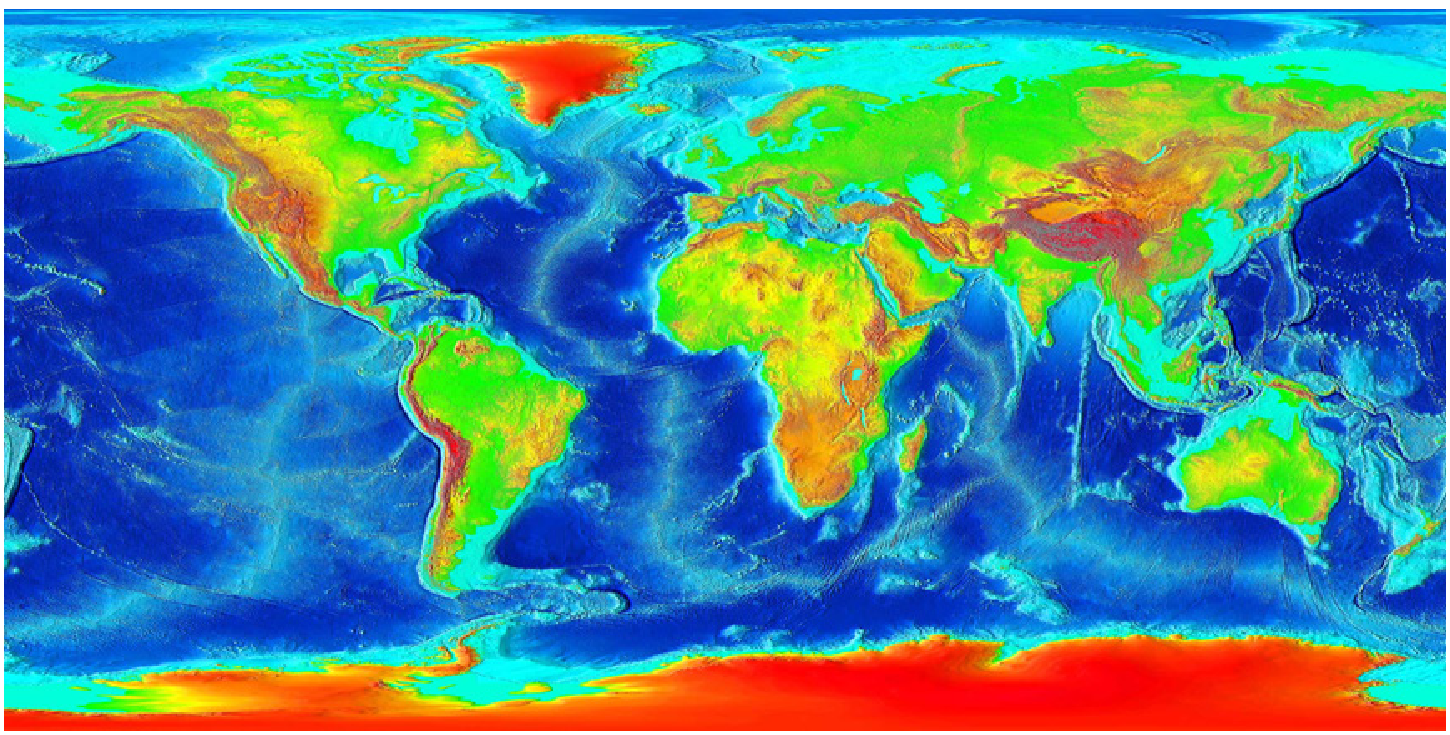

Advancing science learning and teaching for all

NORTH CASCADES AND OLYMPIC SCIENCE PARTNERSHIP

Supported by the National Science Foundation under Grant No. EHR-0315060

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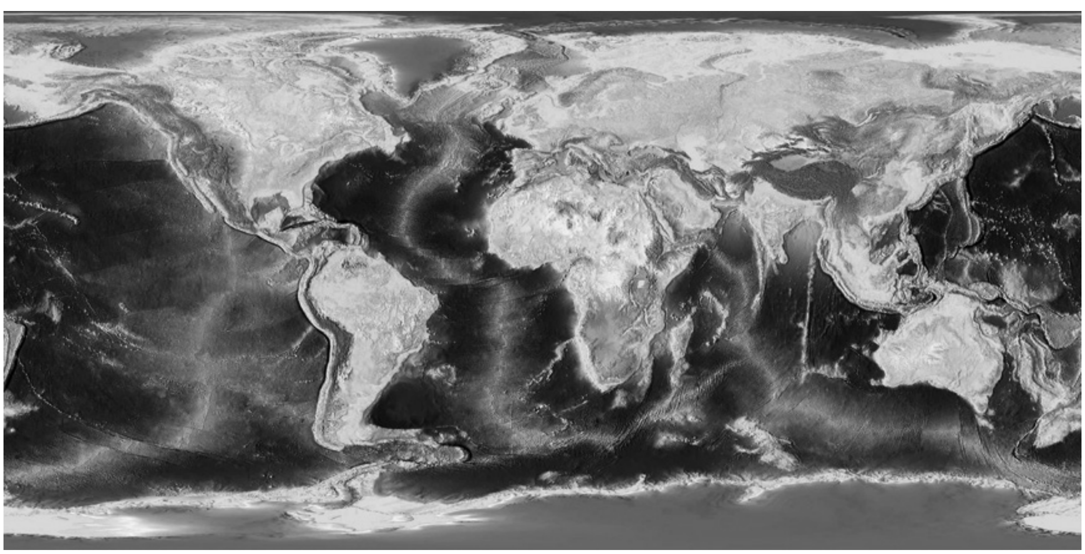
Investigating the Flow *of* Matter *and* Energy *in* Earth Systems



North Cascades and Olympic Science Partnership

Advancing science learning and teaching for all

Investigating the Flow *of* Matter *and* Energy *in* Earth Systems

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NORTH CASCADES AND OLYMPIC Science Partnership

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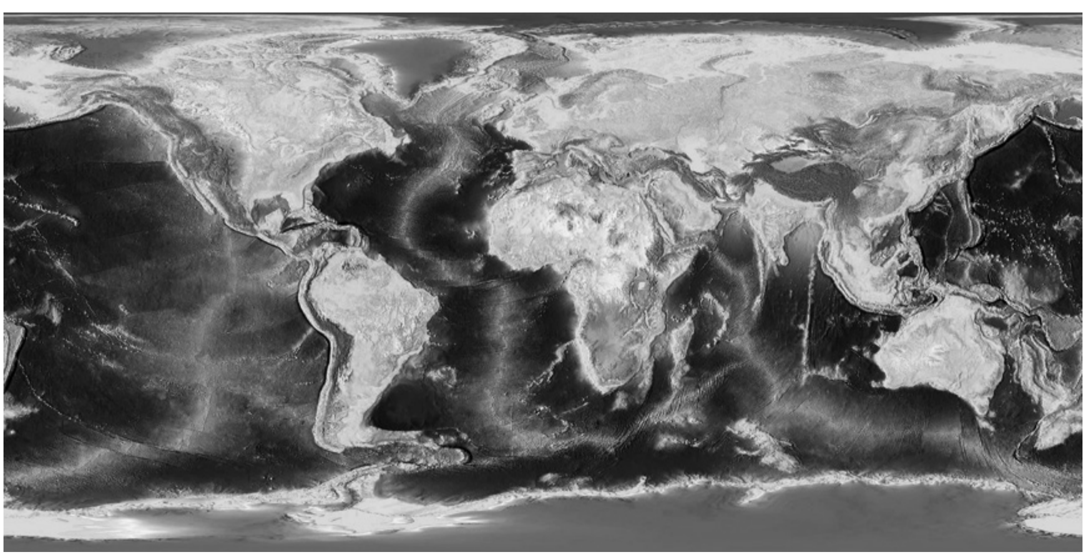
CYCLE 1

How do we know about something if we can't see, hear, or feel it?



CYCLE 1

How do we know about something if we can't see, hear, or feel it?

INTRODUCTION: This (or The GET) curriculum is designed to follow the key research findings described in the "How People Learn" report published by the National Academy of Sciences. Throughout this curriculum you will be asked to examine your own learning. Let's begin by looking at someone else learning. View this short video clip of a 4th grader who was asked some questions about mountains. Share your ideas with your group members (2 or 3 others). Your instructor will now lead a short whole-class discussion about all the groups' ideas and how this applies to this (or the GET) curriculum.

ACTIVITY 1 *Interpreting Patterns*[1]

PURPOSE

Imagine you need to make a decision about something very important in your life. You want to make the decision based on sound scientific judgment. To get to that point, you need to understand something about a scientific way of thinking. This cycle is meant to help you organize your thoughts about what you know about science, and to get involved in a process of analyzing patterns that all scientists use, no matter what their scientific specialty.

Q. What are some aspects of a scientific way of thinking?

INITIAL IDEAS

1. On your own, write down how you think scientific understanding is constructed.

2. You are walking next to a stream and you notice that there are very large boulders in the streambed. You think to yourself, wow, there was a big flood here once to move such big boulders.

On your own, write down which part of your thought process above describes an *observation*. Which part describes an *inference?* What is the difference between the two? Do your best even though you may not know what these terms mean.

Share your ideas with your group members (2 or 3 others).
Your instructor will now lead a short whole-class discussion about all the groups' ideas.

[1]The activity for this cycle is adapted from Activity 1, Chapter 6 of *"Teaching About Evolution and the Nature of Science",* 1998, National Academy Press.

COLLECTING AND INTERPRETING EVIDENCE

STEP 1

Join with two or three neighboring groups (no more than 12 students, no fewer than 6). Look at the small cube in the center of your group, BUT DO NOT LIFT THE CUBE. In the space below, write down your observations about the numbers, and the patterns you observe.

Describe how you interpreted the patterns to predict what was on the bottom of the cube. Describe at least two patterns you used.

STEP 2

In your same group, put the larger cube in the center of your group, BUT DO NOT LIFT THE CUBE. *What is on the bottom of the cube?*

In the process of figuring this out, make sure you:

- Record what you know about the visible sides (observations).

- Record your progression of ideas (hypotheses about patterns).

- Once you have narrowed down the choices, make a PREDICTION for one of the bottom corners of the cube. (You will be able to look at one, but only one, in just a moment).

- Using a mirror and something to tilt the corner of the cube LESS THAN ONE INCH, take a look at one of the corners. Describe how your prediction matches what you saw.

- Discuss what you observed with your group. Now what do you think is on the bottom of the cube? How could you know for sure without lifting the cube up?

Put the cube away and **do not look at the bottom**.

STEP 3. SCIENTISTS' IDEAS

Terms Used in Describing the Nature of Science

Scientists make observations about the natural world. Observations are descriptions of what is sensed through the five senses: sight, hearing, smell, taste, and touch. Observations are something that can be verified as accurate by another person who uses the same methods as the original observer. They are facts and they are repeatable and verifiable.

Scientists also think about the natural world, trying to piece together how it works. They make **inferences,** which are conclusions based upon their observations and their prior knowledge. Given the same set of facts (observations), two scientists could make different inferences. In fact, this frequently happens in science: different groups of scientists have different inferences about how something works and they can sometimes get quite competitive about supporting their ideas! The scientists continue to design experiments and gather data in an effort to decide between the two conflicting inferences.

As scientists develop a particular idea or line of inquiry, they make inferences all along the way. These inferences go by different names, depending on how well supported they are.

OPTIONAL: Your instructor may hand out the "Is It A Theory" probe at this point.

Hypotheses are inferences scientists make as they are beginning to develop an idea. They are useful because they allow the scientist to make predictions and design **experiments** to test the hypothesis.

If the experiments support the hypothesis, it will be kept as a likely explanation. If the experiments do not support the hypothesis, it will be discarded or revised.

Models are inferences about how a process works. They usually take into account many observations. They are useful because they allow scientists to explain observations and also to predict observations that are expected in the future.

Theories are inferences that have stood the test of time and lots of experimentation by different groups of scientists. When people say "I have a theory" in everyday language, they usually mean "I have a guess." This is very different from what a scientist means when they say "I have a theory." A theory in science is accepted as very likely to be true because of all the evidence that supports it. A theory usually incorporates facts, inferences, and multiple well-tested hypotheses.

The contention that evolution should be taught as a "theory, not as a fact" confuses the common use of these words with the scientific use. In science, theories do not turn into facts or laws through the accumulation of evidence. Rather, theories are the end points of science. They are understandings that develop from extensive observation, experimentation, and creative reflection.

So, what is truth in science? Some people think that "scientists are always changing their minds" and are never certain about anything. This is a little bit ironic because science is, at its heart, a quest for truth -- truth about how the natural world works. Scientists are taught to question, to ask for evidence, to push the limits of what is known and understood. The reason that scientists never say an inference is "true" is because they always leave room for future developments and remain willing to push the limits of even the most established ideas. So, ideas do change in science. However, hypotheses are much more likely to change than are theories. Theories, because of the amount of evidence that supports them, are a scientist's version of the "truth." You might call them "truth in progress" because they may be modified or added to as new data is gathered in the scientific quest for knowledge.

Scientists around the world collaborate in this quest for knowledge. Scientists with different areas of expertise may collaborate to bring diverse skills and perspectives together to attack a particular problem. Through scientific meetings and journals, scientists share their observations and inferences with each other so that their work can be verified, challenged, and used to build a larger scientific understanding of the world.

A **scientific law** is not an endpoint in science; it is not the gradual progression of a theory to become a law. A law is a descriptive generalization about how some aspect of the natural world behaves under stated circumstances. The "law of gravity" describes gravity, but does not explain WHY gravity occurs. A scientific theory may incorporate scientific laws.

Below, we summarize some of the ideas that scientists have about the Process of Science. For each of the scientists' ideas listed, write down evidence or examples from your own experiments or other class experiences that would support that idea.

IDEA 1: Observations are facts collected using the five senses. They are repeatable and verifiable.

IDEA 2. Inferences are conclusions made from observations and prior knowledge. Given one set of facts, inferences may vary from person to person.

IDEA 3. Hypotheses are "educated guesses" or explanations about the natural world that scientists make based on their initial observations. Hypotheses can be tested by experimentation.

IDEA 4. If the results of an experiment do not support a hypothesis, the hypothesis must be rejected or revised.

IDEA 5. Science is collaborative and involves the sharing of observations and inferences.

SUMMARIZING QUESTIONS

1. Revisit your initial ideas on observations versus inferences. What is an observation? What is an inference?

2. Record at least three of your group's observations and inferences regarding the name cube in the table below. Be sure to write your final inference regarding the name on the bottom. When you are finished, transfer this table to a whiteboard.

3 Observations	3 Inferences

FINAL INFERENCE: What is the name on the bottom of the cube?

3. Compare the class observations and inferences, including the final inference of the name on the bottom of the cube. Which were more similar between the different groups, the observations or the inferences? Why do you think this is so?

4. Is an inference different from a guess? Explain your reasoning.

5. Find Figure 3-3 in Cycle 3. This figure is a map of the Earth's interior made by earth scientists. Some of the information used to construct this map is as follows:

- Earth scientists have drilled into the Earth and analyzed the material found there to a depth of about 13 kilometers.
- Earth scientists have studied vibrations (waves) in solids and liquids and have seen a different pattern in the way waves travel through these materials.
- Earth scientists have used seismometers to measure earthquake waves as they travel through the Earth. They have seen wave patterns that look like those you get from liquid materials when energy waves hit the outer core of the Earth, indicating that the outer core is liquid.
- Earth scientists have also analyzed the composition of meteorites that were formed around the same time that the Earth was formed in order to determine the types of minerals that are found deep within the Earth.

Which of the findings of earth scientists listed above represent observations and which represent inferences?

Is the map in Figure 3-3 an observation or an inference? Explain your thinking.

Your instructor will now lead a short discussion of the class' ideas on the difference between your observations and your inferences, and how this relates to your scientific investigation. Use your whiteboard from Question 2 in this discussion.

Is the distinction between observation and inference a more critical distinction in Earth Science as compared to other sciences?

ACTIVITY 1: HOMEWORK

Name ______________________________ *Date*______________________

Group ______________________________

Ideas About the Nature of Science

PART 1

In Activity 1 you thought about the difference between observation and inference, and you had the experience of using patterns to make a prediction. Our class discussion may have given us some insight into the process of science.

Now, we will examine some readings to have you think a little deeper about what science is.

To read:

1. Read the following poem *"When I heard the Learn'd Astronomer"* by Walt Whitman:

> *When I heard the learn'd astronomer;*
> *When the proofs, the figures, were arranged in columns before me;*
> *When I was shown the charts and diagrams, to add, divide, and measure them;*
> *When I, sitting, heard the astronomer, where he lectured with much applause in the lecture-room,*
> *How soon, unaccountable, I became tired and sick;*
> *Till rising and gliding out, I wander'd off by myself;*
> *In the mystical moist night air, and from time to time*
> *Look'd up in perfect silence at the stars.*
>
> -Walt Whitman, American poet

Does this poem reflect any of your thoughts about science? Why or why not?

Read Chapter 9 from *"Zen and the Art of Motorcycle Maintenance"* by R.M. Pirsig, 1974, Bantam Books.

2. Is motorcycle maintenance SCIENCE? If so, how? If not, why not? What characteristics distinguish activities that are "Scientific" vs. "Non-Scientific"?

3. Read *"Ten Myths of Science....."* by W. McComas. Now considering your initial ideas and your current thinking, how would you describe how scientific understanding is constructed?

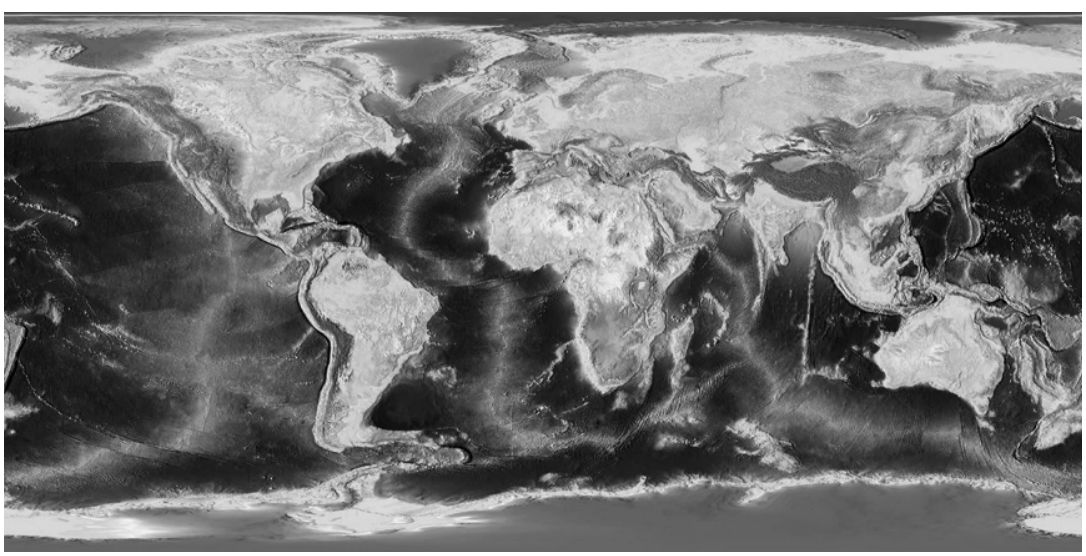
4. Review your initial ideas from the assessment probe on what a theory is. After reading page 11, how have those ideas changed?

PART 2

Go find a fist-sized rock, and do the following: Bring your rock back to class. Write down several observations about the rock in the space below. Next, make inferences about where such a rock could have originated. Finally, what experiments could you conduct to attempt to further confirm your inferences?

CYCLE 2

How do rocks tell us about Earth processes?



CYCLE 2

How do rocks tell us about Earth processes?

OVERVIEW

In this unit we will first examine how Earth can be observed at a variety of scales from atomic to global. These observations, repeated over time, lead us to see that Earth is a dynamic, changing planet.

We will then explore the processes of change that lead to this dynamic environment on Earth. These processes are driven by energy transfers, which we can represent using energy diagrams. All processes of change that occur on Earth involve gain and loss of a limited number of energy forms.

Rock is the matter (stuff) that makes up the solid part of Earth. Almost all rock that we see at Earth's surface was originally formed underground and was uplifted to the surface. Recognition of patterns in our observations of different kinds of rock will lead us to inferences about how and where those rocks formed. We will also learn about how rocks can continuously be transformed into other types of rocks. This continuous cycling of Earth's matter can be described in the rock cycle.

ACTIVITY 1 *Physical Scales of Observation*

PURPOSE

To begin our investigations of the flow of energy and matter in Earth systems, we must first become familiar with how we make observations and inferences about Earth, and how we can understand how Earth changes over time.

Q. How small and how big are our observations of Earth?

INITIAL IDEAS

As a class, view the DVD "Powers of Ten." Can your group find some natural divisions of scale in how you observe nature? Do you use different instruments to examine nature at different scales?

COLLECTING AND INTERPRETING EVIDENCE

We can observe Earth at different scales, from global (thousands of kilometers, 10^6 m) to atomic scale (nanometers, 10^{-9} m). Each of these scales of observation can tell us different things. When we ask questions about Earth, we must figure out what the appropriate scale of observation should be. Review Table 2-1 for the physical scale of observation used by Earth Scientists.

TABLE 2-1 PHYSICAL SCALES OF OBSERVATION USED BY EARTH SCIENTISTS

SCALE OF OBSERVATION	USED TO STUDY THINGS LIKE...	MEASURED IN....	EXAMPLE
Global	Entire planet	Thousands of kilometers (km) or miles	Earth
Regional	Portions of oceans, continents, countries, provinces, states, islands	Kilometers (km) or miles	Lake Michigan
Local (outcrop or field site)	Specific locations that can be “pin-pointed” on a map	Meters (m) or feet	Road cut on I-5
Hand sample (field/lab sample)	Sample of a mineral, a rock, air, water, or an organism that can be held in your hand	Centimeters (cm), millimeters (mm), inches(in)	Rock in your garden
Microscopic	Features of a hand sample that can only be seen with a hand lens (magnifier) or microscope	Fractions of millimeters, micrometers (μm)	Mineral under a microscope
Atomic (or molecular)	Arrangements of the atoms or molecules in a substance	Nanometers (nm)	Sodium atom

Review your ideas from Cycle 1 about the difference between an observation and an inference. Now, look at the images that are being projected in front of the room (Earth from space, satellite image of Mt. Etna, Grand Canyon, rock). For each image, work with your group and fill in Table 2-2. For the physical scale of observation, you can refer to Table 2-1.

TABLE 2-2 IMAGES OF EARTH

IMAGE	What physical scales of observation are represented? (Refer to Table 2-1)	If you could view Earth 10,000 years from now, from this same location and scale, what features would be the same? What would be different?
Image of Earth from space		Same: Different:
Satellite image of Mt. Etna		Same: Different:
Grand Canyon photograph		Same: Different:
Granite, basalt, peridotite		Same: Different:

Does the third column in Table 2-2 consist of observations or inferences? Explain your reasoning.

SCIENTISTS' IDEAS - RELATING SCALES OF UNDERSTANDING

Geologists seek to understand complex relationships of things on Earth relative to human lifetimes and the geologic time scale. To think like a geologist, you must consider many materials and processes over a broad range of time scales and spatial scales of observation. One way to simplify this thinking process is to develop different levels of understanding, from the most general to the most specific. The most generalized way of thinking about Earth is to think of it as a single planet (global scale). A more specific and complex way to think about Earth is to think about individual locations, samples, or even atoms. Of course, materials and processes observed at one scale might not be visible at another scale.

At the global scale of observation, geologists conceptualize Earth as a dynamic planetary system comprised of interacting subsystems. They are lithosphere (rock), hydrosphere (water), atmosphere (air), cryosphere (ice), and biosphere (life).

Observation of materials and processes at more specific scales of observation provides more specific data and levels of understanding. Any comprehensive study of geology involves data collected from several space and time scales, each one linked to the other at some level.

ACTIVITY 2 *Processes of Change Driven by Transfer of Energy*

Earth is characterized by energy flow and processes of change at every spatial scale and time scale of observation. Earth's surface is energized by geothermal energy (from inside the planet) and solar energy (from outside the planet). The energy flows from sources to receivers (materials that store or convert energy) and drives processes of change like the examples in Table 2-3 below.

Note that many of the processes have opposites depending on the flow of energy to or from a material: melting or freezing, evaporation and condensation, erosion and deposition. Such effects cause materials to be endlessly cycled and recycled. Two examples of these cycles are the rock cycle and the water cycle.

TABLE 2-3 COMMON PROCESSES OF CHANGE

Leave the last 3 columns blank until you are instructed to fill them in later in this activity.

EARTH SCIENCE PROCESS	KIND OF CHANGE	EXAMPLES OF THIS PROCESS IN EARTH SYSTEMS	SOURCE AND RECEIVER	TYPE OF ENERGY TRANSFER (ARROWS ON ENERGY TRANSFER CHART)	INTERACTION TYPE
Melting	Sold phase changes to liquid phase	•Glacial ice melts to water in a stream •Rocks inside Earth melt to form magma			
Freezing/ Crystallization	•Liquid changes to solid phase •The formation of a crystal (atoms, ions or molecules arrange themselves into a regular repeating 3-D pattern)	•Liquid magma erupts into the ocean and freezes to glass. •Liquid magma cools and crystallizes underground into a solid mass of crystals.			
Metamorphism	Heat and pressure change rock from one type to another	Deep within Earth, a rock is heated and buried			
Uplift	Regions of rock deep in Earth are moved upwards	Rocks get squeezed and tilted and pushed upwards by regional scale forces			
Chemical Weathering	Earth materials are chemically altered, dissolved, or decomposed	Feldspar crystals react with acidic water to form clay minerals and metal oxides (rust)			
Physical Weathering	The physical breaking down of rock into smaller pieces	Boulders break apart, get worn into pebbles, sand, or clay due to wind, water, roots, thermal expansion, ice			
Erosion/ Transportation	Materials are pushed, bounced, or carried by water, wind, or ice	•Streams push, bounce, and carry materials downstream. •Sand and soil are blown away			
Deposition	Materials are deposited because of decreased energy of transporting agent	Sand is deposited as a river empties into a lake			
Evaporation	Liquid phase changes to gas (vapor) phase	Water in a lake turns to water vapor in the air			
Condensation	Gas (vapor) phase changes to liquid phase	Water vapor in the air turns to water droplets in a cloud			

Class Discussion

Recall the photograph of the Grand Canyon. In your group, discuss which processes of change that would need to occur at the Grand Canyon to cause the different features you listed in Table 2-2 10,000 years from now. You can use the Common Processes of Change table in your Scientists' Ideas as a reference for this. Be prepared to discuss these processes with the class.

INTERACTIONS AND ENERGY ON EARTH: AN ENERGY DIAGRAM PRIMER

PURPOSE

When Earth scientists study Earth they focus their attention on different ways that matter and energy interact, and how energy moves around in the Earth system. Transfer of energy between different subsystems of the Earth systems is what drives all geological processes.

Q. How can energy interactions on Earth be represented?

INITIAL IDEAS

When two objects or systems interact, one often causes a change in the other. For example, consider the following chain of interactions:

Heating of the Earth's surface by the Sun results in warming of the atmosphere, which causes the air to expand, which results in wind that in turn can cause erosion/transportation and ultimately deposition of sediments. These sediments can then be transformed into sedimentary rocks. This example ignores the role of water in the erosion and deposition of sediment.

In this example, there are two main interactions:

1. between the Sun and Earth's surface/atmosphere; and
2. between the Earth's atmosphere and the surface sediments on Earth.

For each of these interactions, what changes occurred in the interacting systems and objects?

Interaction 1: ______________________________

____

Interaction 2: ______________________________

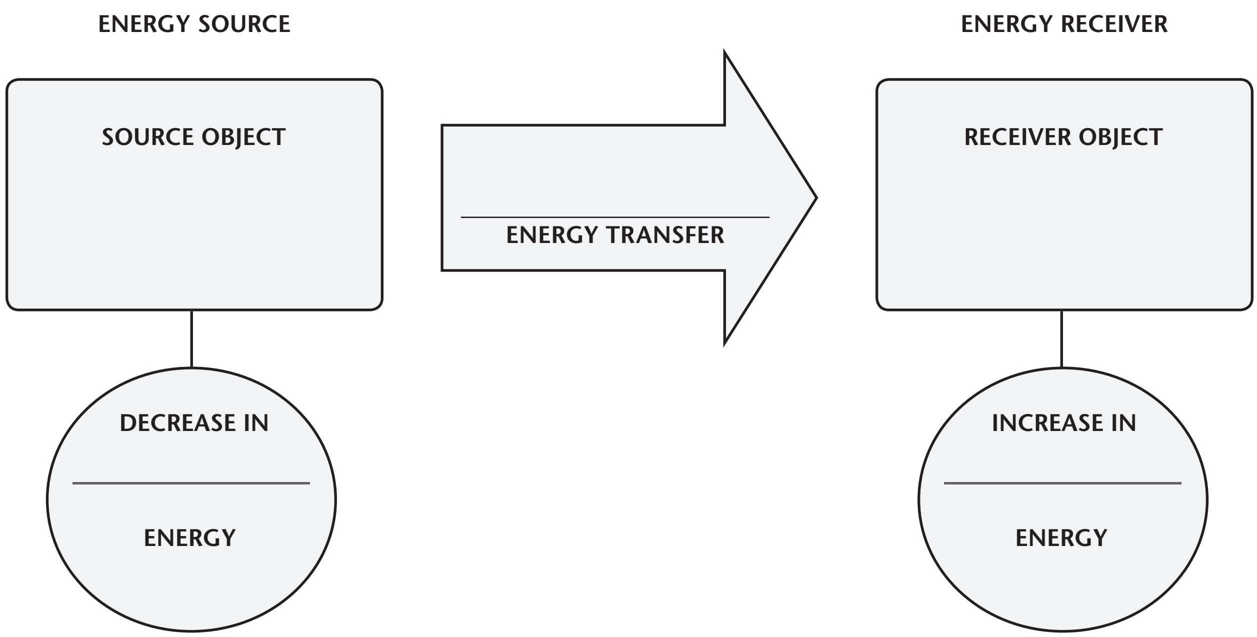
____

In this curriculum you will be examining many different types of interactions. In each case you will collect evidence that supports the conclusion you make about the energy exchanges occurring during the interactions. Because the systems and energy exchanges are complex, scientists develop representations other than narrative descriptions to organize the ideas and interactions.

COLLECTING AND INTERPRETING EVIDENCE

For changes like those described in the initial ideas to occur, energy must be transferred from one system/object to another. The energy source is the object or system that provides the energy. The object or system that receives the energy is called the energy receiver. During the interaction between the two objects, energy is transferred from the source to the receiver. Thus, energy in the source decreases, while energy in the receiver increases.

We can represent this interaction and energy transfer by constructing a source-receiver (S/R) energy diagram. In an S/R energy diagram, the names of the interacting objects are included within rectangles, the type of energy transferred is included in a broad arrow and the energy changes within the objects are included in ovals.



There are many different "types" or "forms" of energy, all are associated with interaction between a source and a receiver. During the interaction between the two objects, energy always transfers from the source to the receiver (or receivers). Therefore the energy in the sources is reduced, while the receivers gain some form of energy. It is possible that during the process of energy transfer, there is also an energy transformation, where the receiver increases in a different type of energy.

For example, when you stretch a rubber band and hold it, the rubber band now has "elastic potential energy". The rubber band was the receiver of energy. When the rubber band is released, the contraction process transforms the elastic potential energy into kinetic energy (the rubber band is moving faster than it was). Scientists' strategy is to think about this process as a sequence of transfers, and in each transfer they try to identify the energy source and receiver.

Consider two stages of this rubber band process and identify the source and receiver in each stage.

1. The rubber band is hooked around a nail in the wall and you stretch the rubber band by pulling it with your fingers.

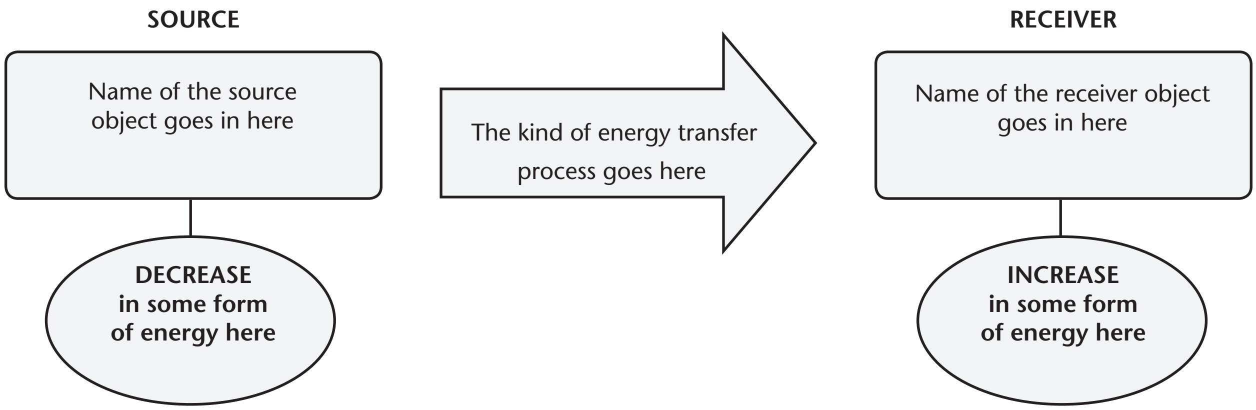
SOURCE	RECEIVER

2. The stretched rubber band is released and flies off the nail.

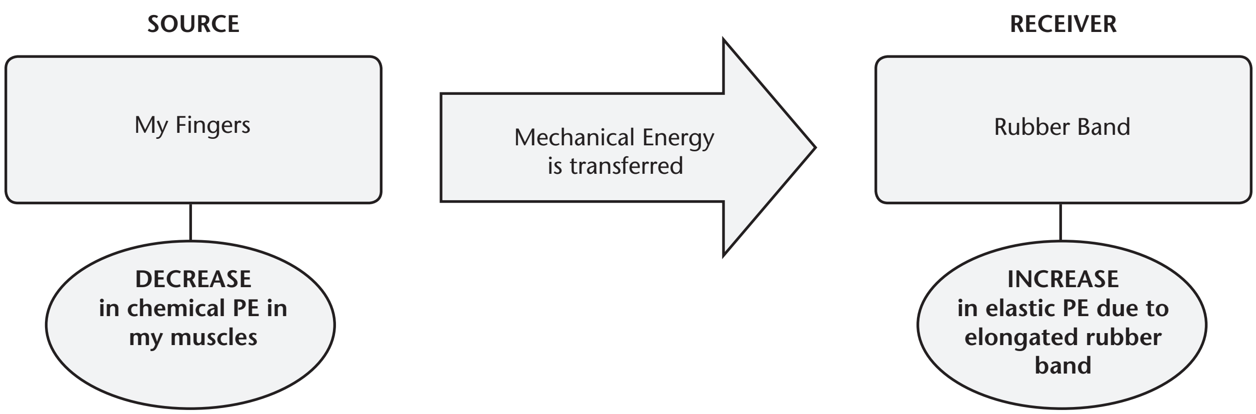
SOURCE	RECEIVER

Check with your group to make sure you all agree with each other.

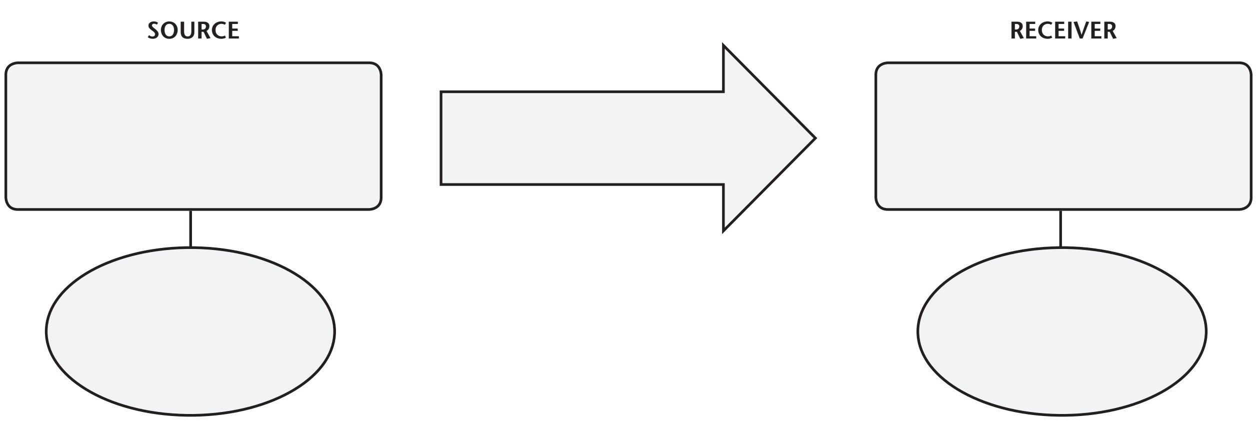
We can represent these interactions and energy transfer/transformation processes by source-receiver (S/R) energy diagrams as have been developed in the Physics and Everyday Thinking courses. In S/R energy diagrams, the names of the interacting objects are included within rectangles. Because there are several different processes that transfer energy, a broad arrow is used to represent the direction of the process and the transfer. During the process the source and receiver undergo changes in energy content. A generic energy diagram including the kind of information written in each element is drawn below.



The diagram for the Stage 1 rubber band stretched by fingers on the nail would look like:

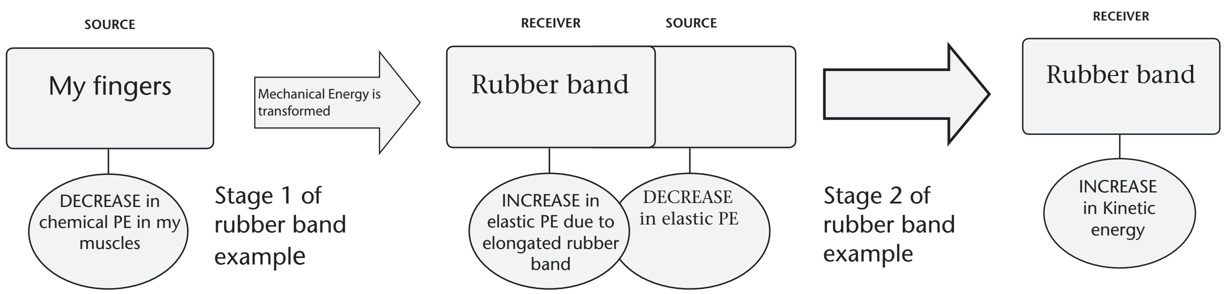


Construct the energy diagram for Stage 2 of the rubber band example. Hint, think about what is different about the rubber band before and after the release.

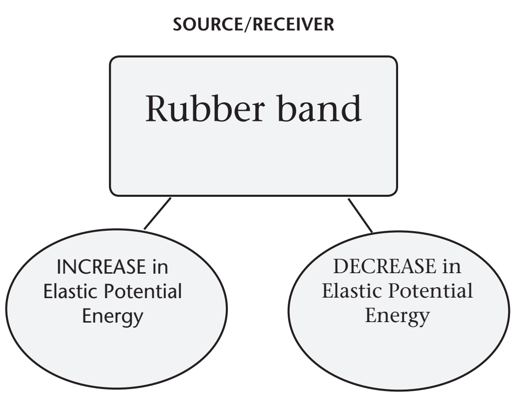


Share your diagram with your group and reconcile your differences. You will not necessarily choose exactly the same words, but your ideas should all agree.

Sequential S/R energy diagrams as well as diagrams that represent multiple energy transformations are easily represented using the basic diagram elements. Linking energy diagrams and branched diagrams allow us to represent more completely what is happening during complex processes. For example, both stages of the rubber band example might be represented in linked diagrams something like:



As you can see this linked diagram is just two S/R diagrams overlapped, which makes a mess of the middle part of the diagram. When thinking about systems involved in energy exchanges the first thing is to figure out the source and receiver object. In linkages, some object or system will likely be both a receiver and a source, as the rubber band is in this example. That object increases its energy in part of the process and decreases it energy in some other part of the process. To simplify this complexity the middle box might be represented this way:



What to put in the ovals? After identifying the source and receiver, we need to determine the **changes in energy** that occur (the ovals). Energy is manifest in nature in many different forms and is evident by direct or indirect observations. Table 2-4 describes some of the most important forms of energy for Earth systems.

What to put on the arrows? Once we have the energy changes in the source and the receiver, we can determine the way the interaction happens. The types of **energy interactions** can be found in the top row of your ENERGY TRANSFER CHART which can be found as a foldout at the back of your curriculum.

TABLE 2-4 FORMS OF ENERGY

Energy Form	Physical Characteristics that give rise to this form of energy	Common Experience of this energy form
Kinetic energy or motion energy	Energy in a system/object due to the motion of the entire mass of the object. The more mass it has, the more KE it has at the same speed	A faster moving object has more KE than the same object moving slowly. A boulder rolling toward you at 1 m/s (~3 ft/s) has more KE than when the boulder is rolling at 0.3 m/s (~1 ft/s). Because of its greater mass, a boulder moving at the same speed as a pebble has more KE.
Thermal energy	Energy in a system/object that is due to the microscopic motion of the tiny particles making up the bulk matter. The total thermal energy of an object is really the total of the KE of the all the particles in it. *Heat is not a form of energy, but it is a familiar term that is associated with energy transfers due to a temperature difference between a source and a receiver. Heat transfer always goes in the energy transfer arrow. It is not a type of energy that is changing during the interaction.*	A hot rock (higher temperature) has more Thermal Energy than the same rock at a lower temperature. The lower the temperature of a chunk of matter, the less Thermal Energy can be extracted from that matter. An object sitting still has no KE, but it definitely has some Thermal Energy. In a Heat transfer process frequently there is a thermal energy change and/or a temperature change in one of the systems involved in the interaction. But it is not always the case that these changes happen.
Potential Energy… general definition	Energy in a system that is due to the separations between the parts of the system. Includes elastic, gravitational, chemical, electromagnetic and nuclear energy.	This energy is not generally evident until some change in the spatial configuration within a system has occurred. This is evident by changes of position of parts of the system.
• Elastic Potential Energy	Energy in materials that can be deformed without breaking, and will reform themselves when released.	Springs, rubber bands and stretchy materials are common. We refer to this behavior as "elastic properties". Surprisingly, matter we think of as rigid is also elastic within some limit. Trees, skyscrapers, and even rock can be bent, compressed, stretched or twisted and when released will reform to their original configurations.
• Gravitational Potential Energy	Energy in a system where enormous amounts of matter are separated from each other by significant distances. Since the earth is a huge mass, it is the dominant matter in earth-gravitational energy changes. When the location or position of a smaller part of the Earth-system is moved significantly, then the gravitational potential energy of the system changes.	Rock slides release large amounts of gravitational potential energy when the large mass of rock moves down a mountain side, closer to the center of the Earth-system. When large plumes of molten rock rise within the magma inside the earth, this rising mass is gaining gravitational potential energy because of the increase in distance between that smaller mass and the center of the Earth-system mass.
• Chemical potential Energy	Potential energy due to the microscopic arrangement of atoms and molecules in matter, therefore this is another form of potential energy.	The gasoline in your car contains this form of energy, while the engine transforms the chemical energy into kinetic energy and thermal energy. When ice melts there is a rearrangement of the water molecules, so there is a difference in chemical potential energy between solid and liquid water.
• Radiant Energy or Electromagnetic energy Higher energy to lower energy X-ray, UV, Visible light, InfraRed(IR)	This form of energy is due to a different kind of change in the microscopic structure of matter that results in emission (or radiation) of a different energy. The name of each radiant energy type is shorthand for the range of energies in the radiation.	When InfraRed (IR) and Visible energy is absorbed it will cause matter to warm up, when emitted it will cause matter to cool. IR absorption is very effective in warming matter and it is the type of radiation used in heat lamps and heating coils. IR and Visible EM radiation energy is lower than UV energy.

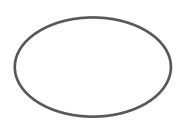
Energy Form	Physical Characteristics that give rise to this form of energy	Common Experience of this energy form
• Nuclear energy	Potential energy due to the subatomic arrangement of matter inside the central core (nucleus) of individual atoms. (This surprisingly miniscule volume of space contains the highest possible potential energy of all of the configurations of matter above. However, the forces that act to keep this matter constrained to the subatomic volume of space are manifestly stronger than the other forces, so it is harder for people to tap into this form of potential energy.)	You have all probably heard of nuclear power. This power is generated by harnessing the energy released during a breakup of the nucleus of an atom. You will learn in Cycle 5 about how naturally occurring radioactivity (emission of ionizing radiation) from the nucleus of an unstable atom inside Earth can transfer heat to surrounding rock. We also have daily experience with nuclear energy in our exposure to sunlight. The source of this radiant energy is from the changes that occur inside the Sun's nuclear material. This is a case of nuclear energy being transformed into radiant energy.
	Waves are not a form of energy; they are one way energy gets transported from one place to another. The movement of energy through matter is because of the some elastic behavior of matter. For waves to propagate there must be some restorative or elastic characteristic in neighboring places throughout the progression.	The motion of the earth surface during an earthquake is the result of the energy passing through the surface as the rock is distorted and returns to its original position. The bobbing of a cork on water as wave energy passes through the water is another way we see some progression of the energy. In this case the motion direction of the wave is not the same as the motion direction of the cork.

Now is a good time to practice constructing energy diagrams. Here is a thinking guide for how to go about this.

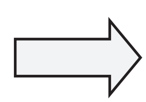
1st: Identify the part of the energy transfer chain you are diagramming

2nd: Identify the energy Source and energy Receiver that are the two interacting systems

3rd: Think about the kind of evidence you might have to infer something about the forms of energy that change in the source and the receiver, this will lead to figuring out the energy forms that go in the diagram. Use the table of energy forms to help identify the types of energy involved.



4th: Think about what is happening during the energy transfer while the interaction is happening. This will help you puzzle out the process(es) involved.



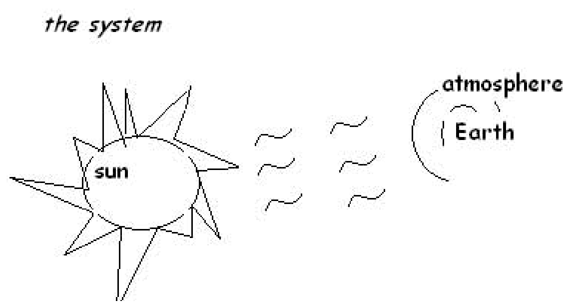
Consider the chain of interactions in the initial ideas at the beginning of this cycle where the Sun light warms the atmosphere.

1st: The energy is treansferred through the space between the Sun and Earth (this hints at radiant energy).

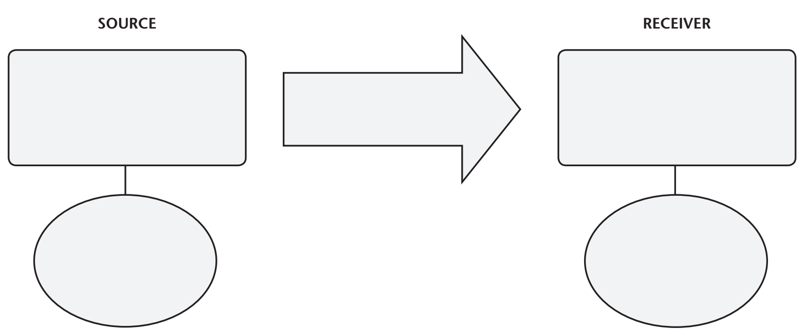
2nd: Clearly the Sun is the energy source and the atmosphere is the receiver.

3rd: The Sun contains nuclear potential energy that is being transformed into radiant energy and the atmosphere is warming up so it must contain thermal energy.

4th: The radiant or electromagnetic or light energy is what is transferred during this process.



Now you can fill in the energy diagram below and compare with your group mates. Check in with your instructor when you are done.



Describe your thinking

Class Discussion

Be prepared to share your diagram with the class.

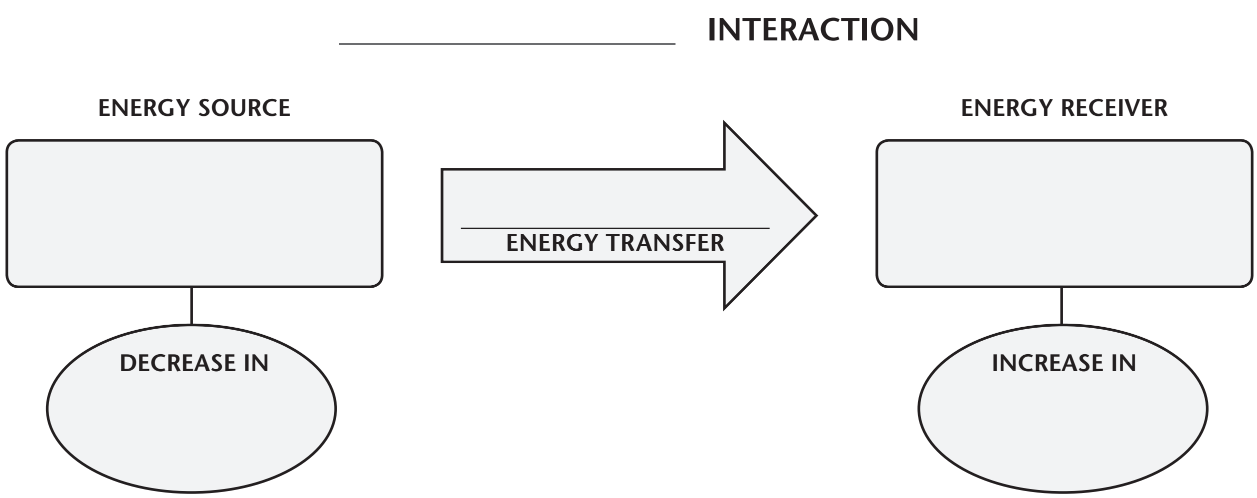
As you continue with this process of documenting energy transfers, it will be helpful to look at the Energy Transfer Chart, which includes more processes than discussed here.

You can continue a chain of energy diagrams to describe what happens next: the atmosphere's thermal energy is converted to kinetic energy, which is then transferred to sediments.

PRACTICE WITH ENERGY DIAGRAMS

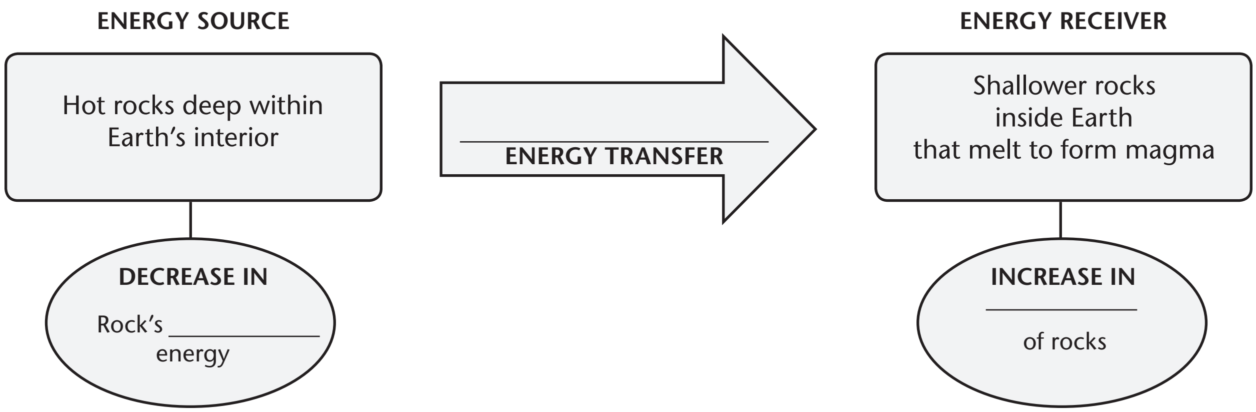
1. Your group should now go back and look carefully at Table 2-3. These are the most common processes of change that you will encounter in this Earth Science curriculum. All of these processes involve energy transfer between a source and a receiver. To practice what we have just reviewed about energy diagrams, your group should fill in a possible source and receiver (Column 4), a type of energy transfer (Column 5), and an interaction type (Column 6) for each process. You may be unsure of some of these at this point, but go ahead and write down what you can. Use Table 2-4 and the Energy Transfer Chart in the back of your curriculum to guide you in your thinking. On this chart you have five possible types of energy transfer, and ten possible interaction types.

2. Working with your group, think of a situation in which energy is transferred within Earth's system. If you have already done Cycle 2, Act 2 homework, then use that photo as inspiration. Now fill in the diagram below. Use the Energy Interaction diagram as a reference.



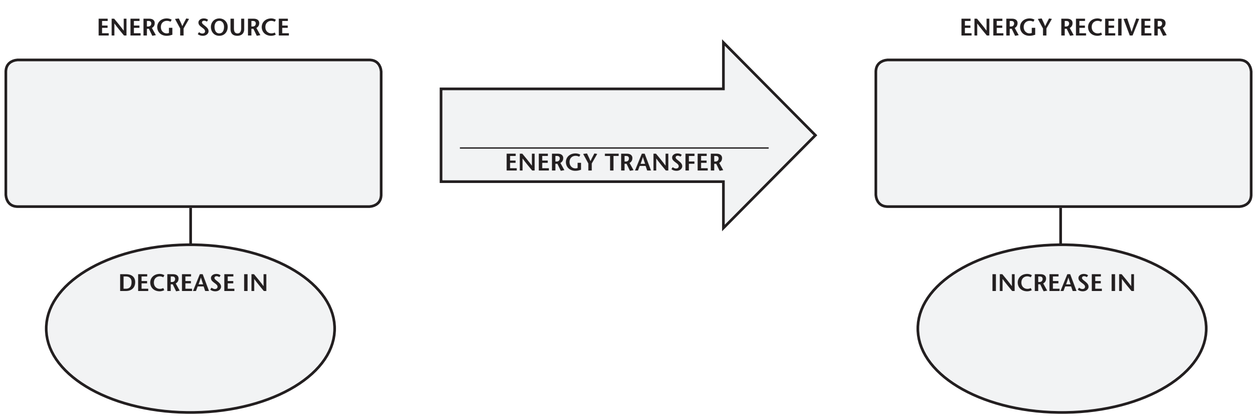
Explanation:

3. Given what you have learned about Earth's system and the transfer of energy, think about the energy transfer involved in the eruption of Mt. Etna that you saw earlier in this cycle. In the diagram below, describe the energy transfer between the hot deep solid interior of Earth and the shallower rocks that melt to form the magma (lava) that erupts from Mt. Etna.



Explanation:

4. Can you draw another energy diagram that involves a transfer of energy from Mt. Etna's lava to the atmosphere after the lava erupts?



Explanation:

Class Discussion

Write down your two energy diagrams from #3 and #4 on your group whiteboard, and participate in a class discussion on the use of energy diagrams for Earth processes.

ACTIVITY 2: HOMEWORK

Name ______________________________ *Date*______________

Group ______________________________

PURPOSE

You have already seen how your observations can lead you to make inferences based on photographs. Now it is your turn to go out into the real world and make observations of your own.

COLLECTING AND INTERPRETING DATA

YOU WILL NEED

- a digital camera or a sketch pad and pencil

STEP 1

Go outside and take a picture of a geologic process in action (geological process as in Table 2-3). If you don't have access to a digital camera, you can sketch it. Be sure to include your photo or sketch when you turn this in.

What did you observe? (Save inference for later)

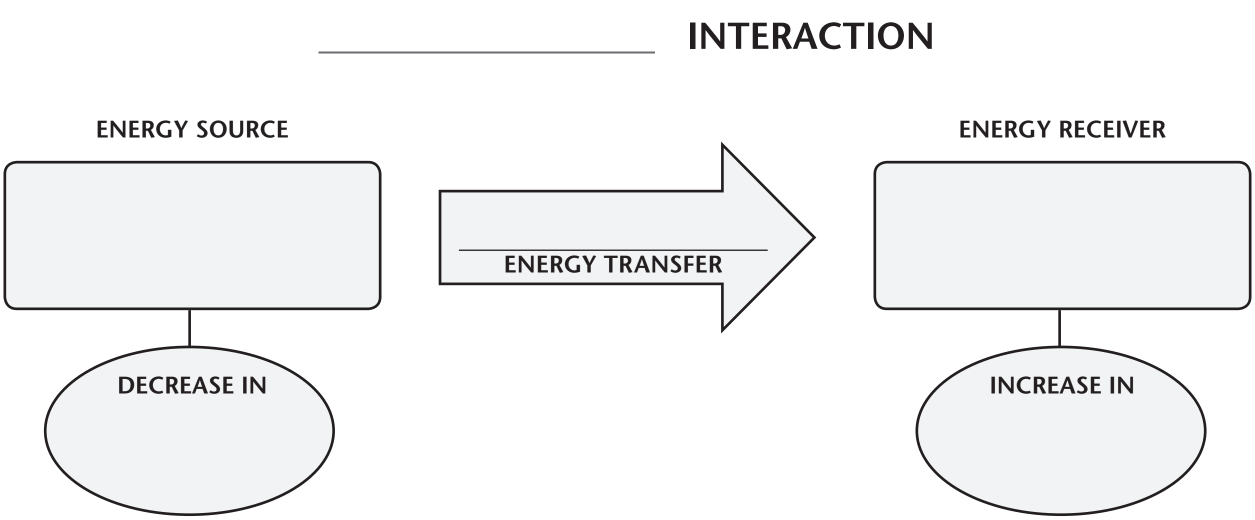
What physical scale of observation is represented in your photo or sketch? (Refer to Table 2-1)

If you could view this same scene from the same location in 10 years, what would be the same? What would be different? How about in 1,000 years? 100,000 years? Next take a stab at 10 million years; what kind of changes could occur in that time frame?

List each process of change from Table 2-3 that you can infer in your photo or sketch, and say why you inferred it.

Where do you think the energy came from to cause the process you observed? Explain your reasoning.

Now, see if you can come up with an appropriate energy diagram for the process you observed. Depending on your process, this could be very complicated. You won't be graded on your accuracy, just on your effort.



Explanation:

ACTIVITY 3 *Discovering Rocks*

PURPOSE

Everything is composed of matter and there are many ways to describe matter. In the realm of chemistry, scientists start with elements, i.e. oxygen and hydrogen, to divide and identify matter. All things are made of elements including minerals and rocks. Energy interactions such as in Table 2-3 lead to the formation of all rock. These rock-forming processes happen beyond the realm of human experience, that is, below Earth's surface. If we can **observe** and **describe** the components within a rock we can then attempt to make an **inference** about how and where the rock formed. This information will allow us to make further inferences about Earth's history, *because every rock has a story to tell.*

Q. What are rocks composed of? How do the components of a rock relate to how the rock formed? How many rock-forming processes are occurring at any time on Earth? Where are

INITIAL IDEAS

On your own explore your initial ideas about rocks by doing these three items on this page. Please, do not turn to the next page until you join your group for a Group Discussion.

1. Scan your memory for images and names of rocks you have **observed** throughout your life. Make a list of any rock names that come to mind, even if you have not seen them. Don't worry if it spelled right or if you are not sure it is a rock or not, just make a list of what comes to mind.

2. Come up with **inferences** as to how one or more of these rocks may have formed.

3. Science teachers commonly use an **analogy** to represent something that cannot be recreated in the classroom. Can you think of an analogy for some type of rock? Hint: the analogy might be a human-made material that is similar to a rock.

Discuss your initial ideas with your group and add new ideas to your responses.

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *How do we describe different components in Plaster of Paris mix?*

As a group you are now ready to take the next step. Maybe someone in your group came up with concrete as an analogy for a rock. Let us explore how we can use Plaster of Paris mixed with sediment as an analogy for rock.

EACH GROUP WILL NEED

- Plaster of Paris
- different grain size materials (e.g., fine sand, coarse sand or gravel)
- three small (~2 oz) disposable containers per group of four students

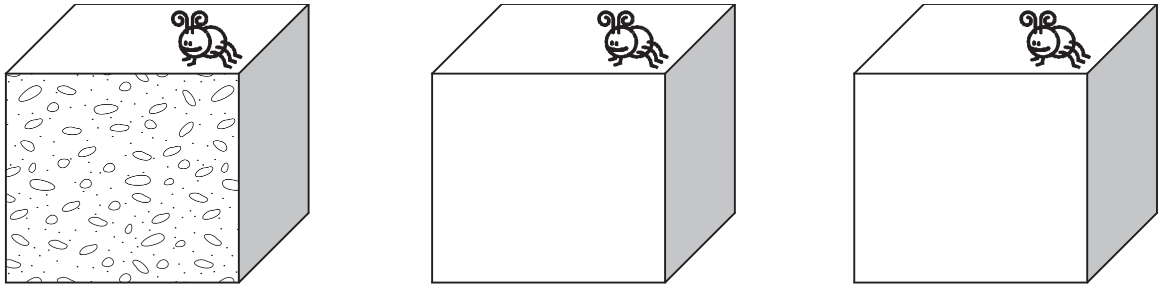
Mix three batches of Plaster of Paris and water in the small disposable containers until it is a pasty consistency. In the first container, add a teaspoon of fine sand. To the second container, add a teaspoon of coarse sand. Leave the third container as is.

Let dry overnight, then remove the solidified mixtures from the container and break in half. Observe the texture, and answer the following questions.

You will need to come back to answer these questions later:

1. What are the ingredients, or components that you observe?

2. Are all your Plaster of Paris samples the same? If not, how are they different? The three block diagrams below are different slabs of Plaster of Paris. The bug is standing on the finished surface. The pattern on the vertical surface shows the largest component, gravel, in the Plaster of Paris. Use the second and third block diagrams below to sketch what the inside of your other samples look like, that is Plaster of Paris made of different size and shaped components.



EXPERIMENT 2 *How do we describe different sizes and shapes of components in concrete?*

Please look closely (maybe more closely than you care to) at the concrete in the places outlined by your instructor. Draw a *labeled* sketch of what you see. If you don't know the names of things in your diagram for the labels, then make something up that is descriptive.

Sample 1 - Description and Sketch

Sample 2 - Description and Sketch

Sample 3 - Description and Sketch

What is different about these three samples of concrete? What is the same? You may use a Venn diagram to show this.

Class Discussion

Class Discussion: What observations did you make about the concrete and the materials in concrete? What kinds of words did you use to describe the materials in the concrete? How were the three samples the same or different?

EXPERIMENT 3 *How can we use rock characteristics to interpret rock origin?*

We will now get our hands on "real" rocks and focus our observations on the *components* of each rock, just like the components that make up concrete.

DISCOVERING ROCKS JIGSAW DIRECTIONS

To investigate the nature of rocks, we will complete a jigsaw, a cooperative learning strategy that incorporates peer teaching.

Part 1 - You will start in a Rock Cycle Group, your "home group" that consists of at least four members. Within each Rock Cycle Group, each member will be assigned to become a specialist in one of four Rock Specialty Groups.

Part 2 - Your Rock Cycle Group (home group) will split up and you will join a Specialty Group where you will **observe** and make detailed descriptions of your assigned rock type.

Part 3 - You will return to your Rock Cycle Group (home group) and share the information you learned about your rock type while in your Specialty Group. After sharing all the information, each Rock Cycle Group will make an attempt to **infer** how and where the different rock types form.

Part 4 - You will explore Scientists Ideas about rock formation, and relate that information to your observations. Your group will construct a table that relates rock type to physical characteristics and processes of formation.

The information shared by each representative of a Rock Specialist Group is a critical link in developing our understanding of the rock cycle, how rocks relate to plate tectonics, and how rocks tell a story of Earth's history.

JIGSAW EXPECTATIONS

- **Cooperative expectations** — all members will participate fairly and equally in all discussions. Everyone should get a turn to speak. Make sure that each group member can summarize the group discussion.
- **Individual accountability expectation** — each group member learns their part well to teach to his or her home group. Individual accountability includes listening skills and asking clarifying questions.

PART 1 In your home group - your Rock Cycle group

CHOOSE YOUR SPECIALISTS

Assign each member of your home group to one of the four Rock Specialty Groups. Organize your group on the table below. Write in the first name of each student and check one of the Rock Specialty Group boxes. There needs to be at least one student per Rock Specialty Group. If your home group has more than four students have them double up in anyway they choose. In Part 2 of this jigsaw you will break up and each Rock Specialty Group will join members from other home groups to form the Rock Specialty Groups and focus their attention on **observing** and **describing** rocks. Finally, in Part 3 the Rock Specialists will return to their home groups and share their observations.

STUDENT NAME	ROCK SPECIALITY GROUP (A, B, C, D)
______________________	______________________
______________________	______________________
______________________	______________________
______________________	______________________

Each Rock Specialty Group (A, B C & D) is designed to represent a type of rock that forms from a particular process and in a particular location on Earth's surface or in Earth's interior. After working with the Specialty Group you will take your recorded observations and one of the rocks back to your home group and proceed with Part 2.

PART 2 Assemble in your Rock Specialty Groups

OBSERVATION AND DESCRIPTION

Obtain a set of rocks. Each rock in the set may look a bit different but all of the rocks are variations of the same type of rock. Observe carefully the components that make up each rock. After the group agrees on a way to describe the physical characteristics of each rock, record the descriptions on the table below.

Table 2-5

ROCK LABEL (I.E., A1, A2 ...	DESCRIPTION OF THE COMPONENTS OF THE ROCK AND HOW THEY ARE ARRANGED IN THE ROCK

CONSENSUS AND INFERENCE

Place your complete set of rocks in front of you. Arrange your set into an order that represents the spectrum of characteristics that you observed. You could line up the rocks or separate them into subgroups. Using your observations and written descriptions, come to a group consensus for a general description for your rock group.

Use the space below to write the paragraph.

CHECK POINT 1: Explain your spectrum of characteristics to your instructor and then he/she will prepare your group for the next step.

Finally, attempt to formulate an **inference** for how these rocks formed. Where did these rocks form, at Earth's surface or in Earth's interior? What was the rock formed from? What conditions of temperature and pressure might be involved?

PART 3 Assemble into your Rock Cycle Groups

STEP 1. SHARING OBSERVED ROCK SPECIALTY DESCRIPTIONS

Return to your Rock Cycle Group with your descriptions and one of the rocks you described. Each group member will take a turn at describing their rock to the other members of your Rock Cycle Group. Each group member should use the chart below to record a description for each of the four rock types. You may want to use an extra sheet of paper.

Table 2-6

ROCK TYPE	CONSENSUS DESCRIPTION FOR EACH ROCK TYPE	SKETCH
A		
B		
C		
D		

CHECK POINT 2: After your group has completed Step 1, share your consensus descriptions with your instructor and then he/she will confirm if you are prepared for "Exploring Scientists Ideas" in Part 4.

STEP 2. RELATIONSHIP BETWEEN ROCK FORMING PROCESSES - INITIAL IDEAS

Discuss with your Rock Cycle Group the formation of each rock. Speculate on how each rock formed. What materials did each rock form from? Where did each rock formation process take place relative to Earth's surface and interior?

Table 2-7

ROCK TYPE	HOW AND WHERE EACH ROCK TYPE FORMED
A	
B	
C	
D	

PART 4 Exploring Scientists' Ideas about Rocks

YOU WILL NEED

- access to the internet

Using the online USGS Geologic Glossary, investigate definitions for the following terms on this and the next page. On the web page there will be a "MORE DETAILS" button after some of the definitions, be sure to click on it to get more information.
http://www.nature.nps.gov/geology/usgsnps/misc/glossaryAtoC.html

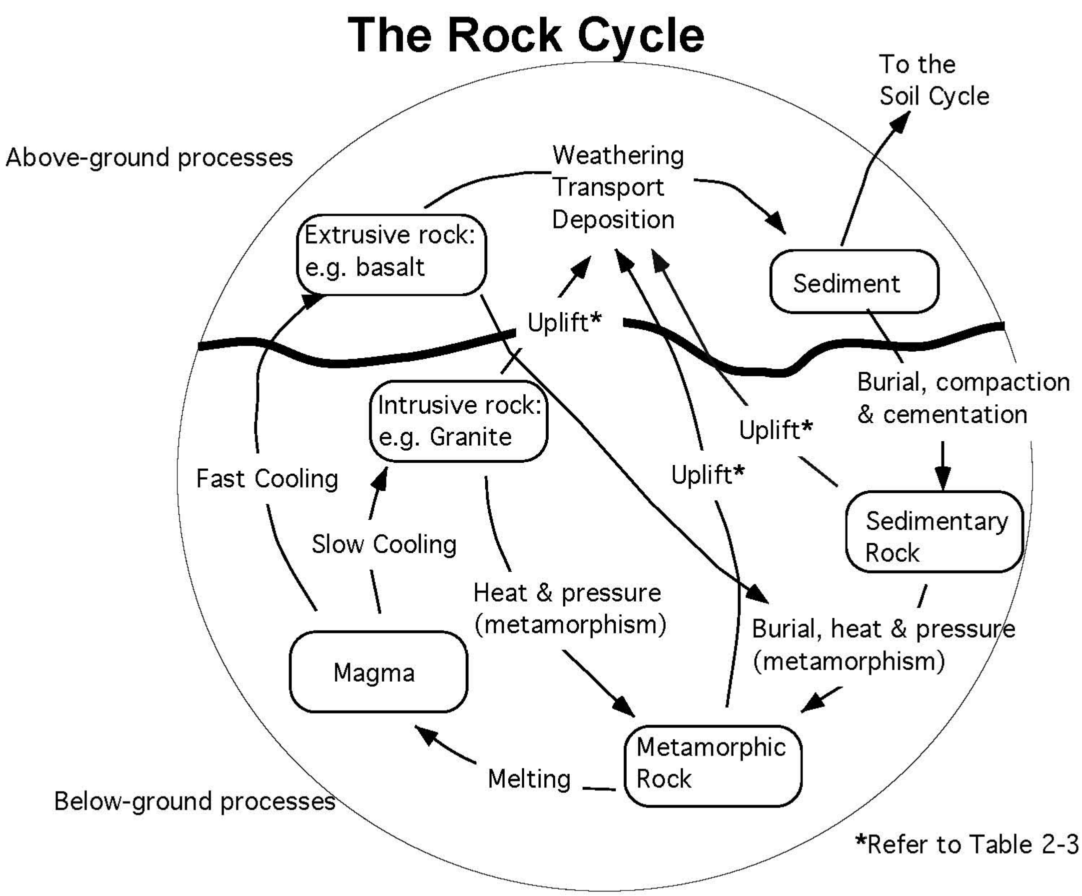
Describe the processes that would produce the four rock types you described in this Cycle.

Table 2-8

ROCK TYPE	PROCESS OF FORMATION
Igneous volcanic/ Extrusive Rock	
Igneous intrusive rock	
Metamorphic rock	
Sedimentary rock	

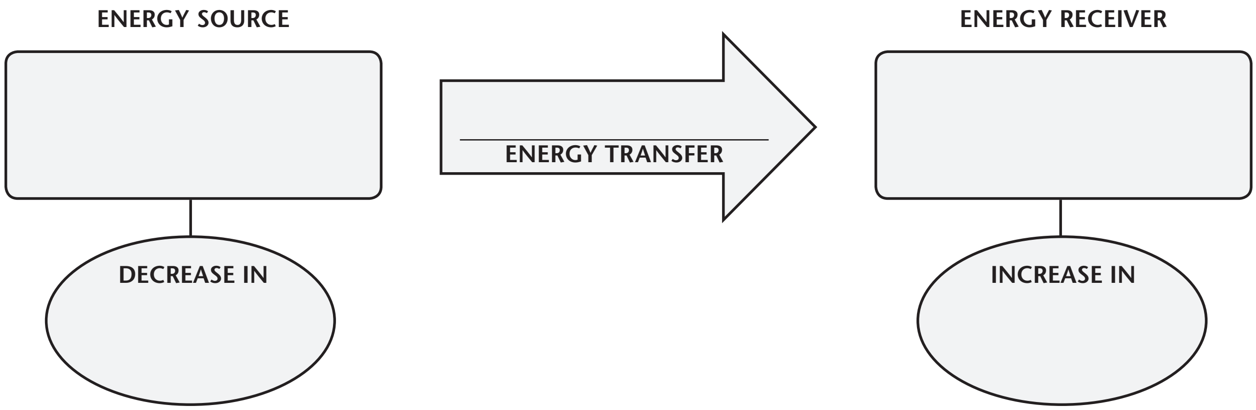
THE ROCK CYCLE

The **Rock Cycle** can be summarized as a diagram of materials (boxes) and processes (arrows) that produce each of those materials. For example, **Intrusive Rock** (which is a type of igneous rock) can become sediment by uplift followed by weathering and erosion. Sediments can become **sedimentary rock** by the processes of compaction and cementation. **Sedimentary rock** can become **metamorphic rock** by burial and metamorphism (heat and pressure). Likewise, **Extrusive rock** can become sediment, or it can get buried and become metamorphic rock. **Metamorphic rock** can be uplifted to become sediment or get melted to become magma.



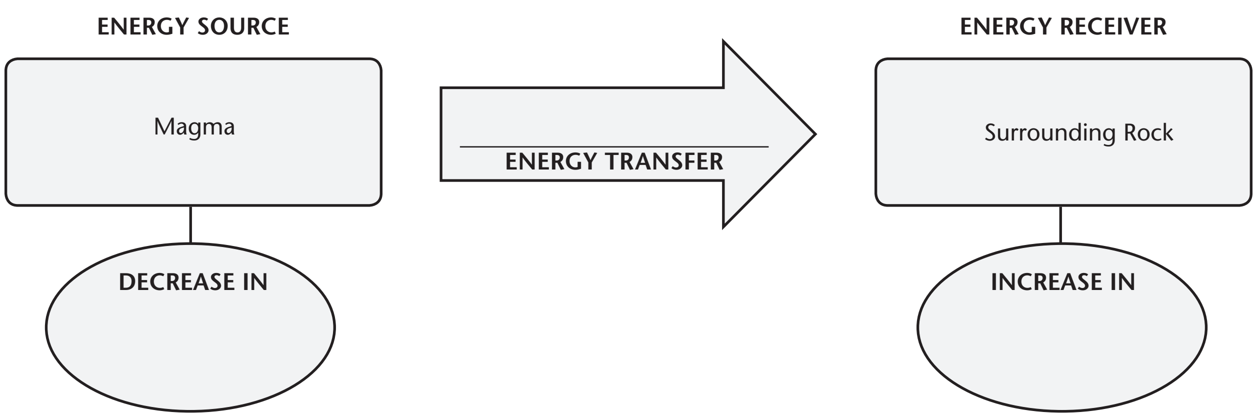
Note that rocks do not have to follow any particular path, but can take a "short cut" across the Rock Cycle. For example, a Metamorphic Rock can become Sediment without first becoming Magma or Igneous Rock. However, it must be uplifted to Earth's surface in order for it to undergo weathering, erosion transport, and deposition as new sediment.

What kind of energy transfers do you think are responsible for melting a metamorphic rock to create magma? Hint: you might want to think about the *metamorphic rock* as the receiver in this one.



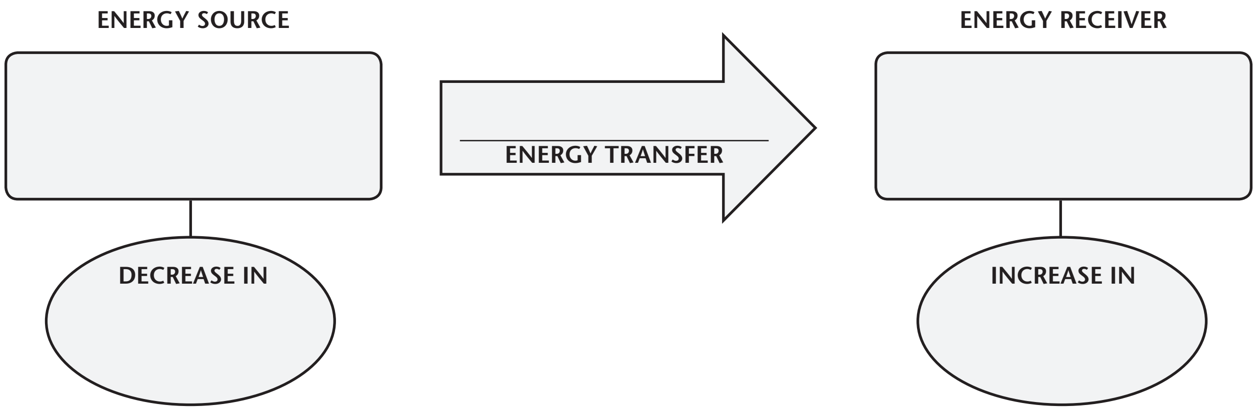
Explanation:

What kind of energy transfers are responsible for cooling of a magma to become an intrusive rock?



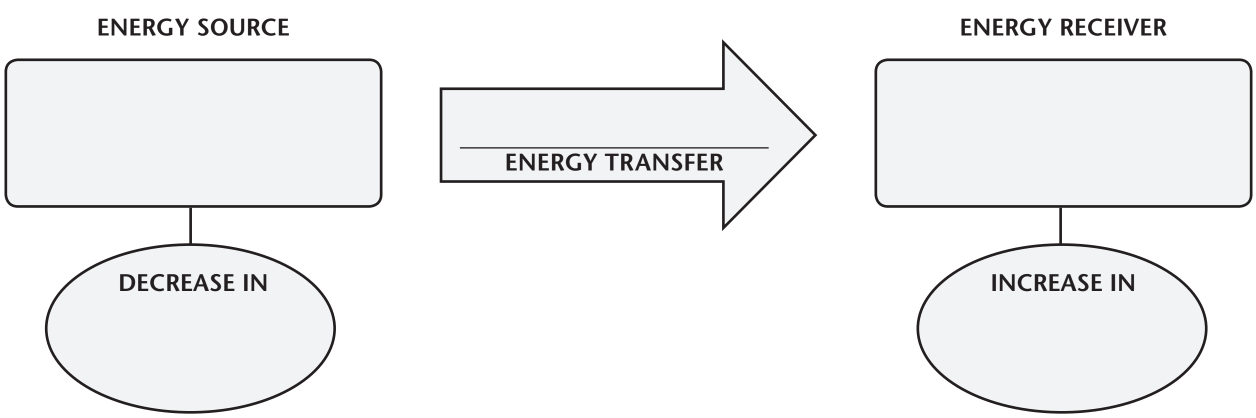
Explanation:

What kind of energy transfers do you think are responsible for creating metamorphic rock from a sedimentary rock? Hint, you might want to think about the *sedimentary rock* as the receiver.



Explanation:

Finally, thinking back to the processes discussed in Cycle 2, Act 2, can you fill in an energy diagram that conveys the energy transfer when moving water sets sediment into motion?



Explanation:

CHECK POINT Check in with your instructor

PART 5 Relating Scientists' Ideas to rock characteristics

Go online to find the following terms used by scientists to name the physical characteristics in the rocks you described in this Cycle. For each characteristic, describe what you would observe in a rock, then infer the process from the rock cycle diagram that would produce it. Each term will relate to only one rock type.

Table 2-9

ROCK CHARACTERISTIC	WHAT WOULD YOU OBSERVE IN A ROCK THAT EXHIBITS THIS CHARACTERISTIC? SKETCH TO ILLUSTRATE IF HELPFUL FOR YOU TO VISUALIZE	WHAT ROCK CYCLE PROCESS CAUSES THIS CHARACTERISTIC	WHAT ROCK TYPE IS THIS CHARACTERISTIC REPRESENTATIVE OF?
Foliated			
Clastic			
Fossil-Bearing			
Aphanitic			
Phaneritic			
Porphyritic			
Glassy			
Vesicular			
Well-sorted			

Write down the terms geologists use to describe each of your rock types, and summarize how each rock type formed.

Table 2-10

ROCK TYPE	WHAT ROCK TYPE IS IT? (extrusive, intrusive, metamorphic or sedimentary)	WHICH PHYSICAL CHARACTERISTICS ARE DEFINITIVE FOR THIS ROCK TYPE? (see table 2-9 to describe what you saw in the rocks)	SUMMARY FOR HOW THIS ROCK TYPE FORMED (use the rock cycle diagram for reference)
A			
B			
C			
D			

After filling in this table, your group should go back to trays A, B, C,and D and make sure you are convinced that all the rocks in each tray exhibit the characteristics you would expect to find for that rock type.

SUMMARIZING QUESTIONS

1. On your own define what a rock is, using your understanding of extrusive, intrusive, metamorphic and sedimentary rocks and how they form.

2. What physical characteristics are distinctive for each rock type, and how are those characteristics formed?

Share your individual answers to questions 1 and 2 with your group. Agree on a single group definition of "rock" that can be shared with the class. Then, form a group summary of physical characteristics of each rock type and how those characteristics are formed.

During your discussion select a group member to record all the questions that come up about rocks and how they are formed. As a group, select two of the questions that remain unanswered to share with the class.

Prepare a whiteboard that illustrates your group's answers to Summarizing Questions 1 and 2. Your instructor will probably assign you a specific rock type to illustrate for Question 2. Share your remaining questions with the class.

PART 6 Rock Cycle Story

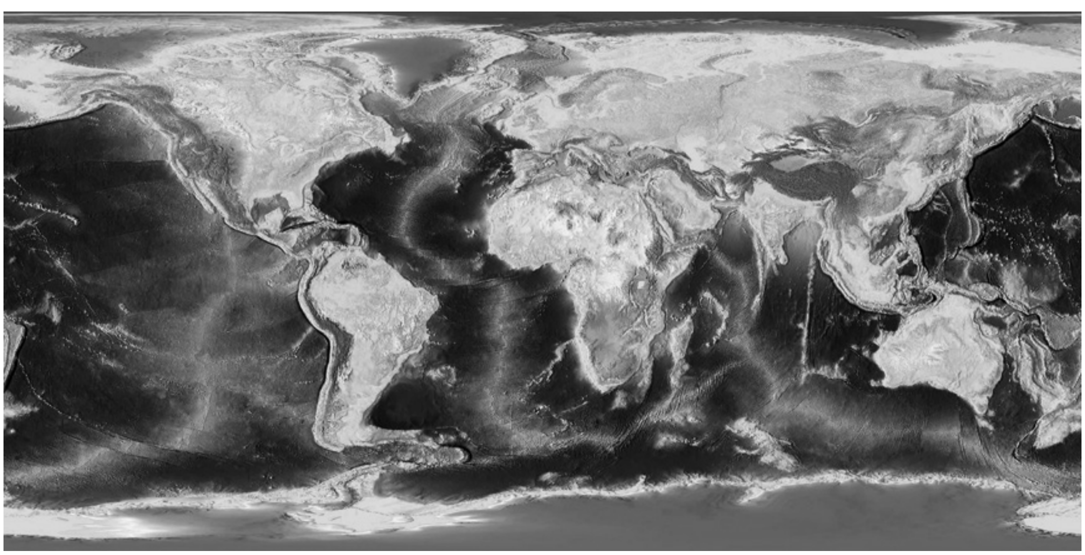
Your instructor will now hand your home group a set of 4 rocks. Please tell a story or prepare a skit that tells a story about how these rocks each formed *from each other* as part of the rock cycle. Be sure to represent the time it takes for rocks to change along the arrow paths on the rock cycle diagram. Before you present your skit, check in with your instructor on your rock identification. As you present your skit, your audience will map the processes you describe on a blank rock cycle diagram.

PART 7 (Optional) Practice with unknown rocks

Your instructor will give you a selection of rocks. Use the rocks' characteristics to define what kind of rock they are and how they are formed.

CYCLE 3

Why does Earth have such varied topography?



CYCLE 3

Why does Earth have such varied topography?

OVERVIEW

In this unit we will explore how Earth materials such as rocks can be measured at the small scale and, from this, make inferences about global topography on a grand scale. Topography is the highs and lows in elevation on Earth's surface. Measurements, of density in particular, become the observations that lead to inferences about why the surface of Earth has deep ocean basins and high elevation continents.

During the following activities, you will have practice making some of the most basic measurements that Earth scientists make: measuring or calculating length, area, volume, mass and density. Relative densities of materials will govern how high a material floats in a "fluid" such as the taffy-like mantle of Earth.

By the end of this cycle, you will see why density is such a critical concept for understanding global topography. In particular, the density and thickness of Earth's rocks can be used to explain why continents have high elevations and Earth's ocean crust has low elevations.

Q. What observations about Earth's topography can we make?

INITIAL IDEAS

On your own, use the 3-D glasses to look at the 3-D bathymetric/topographic map provided to your group. Write down three observations, each at a different scale (small section of the map, medium section of the map, entire map) that tell you something about the Earth's surface (both below and above sea level).

What do you observe about the average elevation of the ocean basins compared to the average elevation of the continents? Why do you think they are different?

Share your answers with your group and write down any new ideas underneath your "on your own" answers.

ACTIVITY 1 *Measurement*

PURPOSE

Making accurate measurements is a critical part of the process of doing science. Measurements are the "observations" of Earth Scientists. Without accurate measurements, how could we recognize and decipher patterns and make inferences? In the following activity, you will review some measurements that you have been using since you were in elementary school, and then expand your understanding of those measurements to include density.

Q. What are some of the various ways that we measure things?

INITIAL IDEAS

YOUR GROUP WILL NEED

- 2 cubes
- 2 graduated cylinders
- lump of modeling clay
- beaker of water
- tweezers (long enough to reach top of water in graduated cylinder)

1. Inspect (pick up and feel) the two cubes that are set up at your table (you might need to share with another group). Fill two graduated cylinders to the same water level, about 1/2 full.

   Predict how the water levels in the graduated cylinders will compare after a cube is placed in each. Assume both cubes will sink. Explain your reasoning for your prediction. Don't actually put the cubes in the water; this is only prediction at this point.

2. Inspect the lump of modeling clay at your table. Predict whether the clay will sink or float when it is placed in a beaker of water. Explain your reasoning.

3. Next, predict what will happen to the clay if a smaller piece of clay is broken off the larger lump and placed into the water. Explain your reasoning.

On your group whiteboard, discuss and record your group's predictions for questions 1 - 3 above and be prepared to explain your reasoning.

DON'T TEST YOUR PREDICTIONS UNTIL YOU READ THE INSTRUCTIONS BELOW

After the whiteboard - class discussion, go ahead and test your predictions for questions 1-3. Were your predictions validated?

Important Instructions:

1. When you carry out your tests, tilt your cylinders as you put the cubes in so that you don't create a splash and lose water.

2. If you are testing a really small piece of clay, use something like tweezers to put it all the way underwater and then let go (this is so that surface tension doesn't interfere with your observations).

Question 1. Water levels and cubes

Question 2. Clay - sink or float

Question 3. Smaller clay pieces

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *Properties of Materials*

YOUR GROUP WILL NEED

- 1 set of six or seven balls
- metric ruler
- two graduated cylinders (250 mL and 500 mL)
- two gram balances (0.1 g accuracy and 1 g accuracy)
- small lump of modeling clay
- calculator
- marshmallows
- small piece of rock

STEP 1

Obtain a set of balls from the supply table. First, sort the balls by heaviness (heft). Sketch your results:

Second, sort the balls by how much space they take up. Sketch the results:

Did you end up with the same organization of balls with the two different ways of sorting? Why or why not?

Discuss your results with your group.

STEP 2

MASS

In Step 1, you sorted balls by their heaviness or heft. We call this property an object's **mass**. Mass is the amount of stuff in an object. The weight of an object depends on the pull of gravity on that object. You can use a gram balance to measure the mass of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of measurement of mass in the metric system, but instruments used to measure grams vary from triple beam balances to spring scales to digital balances.

For the purposes of this class, we can interchange mass with weight. Strictly speaking, this is not correct, because an object's weight depends on the pull of gravity, whereas its mass does not. But for this course, we are rooted firmly on Earth and use an object's weight as a representation of its mass.

Measure and record the mass (weight) of the two cubes that you looked at in #1 of the Initial Ideas.

VOLUME

In Step 1, you also sorted the balls by the amount of space they took up. We call this property the object's **volume**. We measure volume in cubic centimeters (cm^3).

You can measure an object's volume with a ruler (length **x** width **x** height) if it has regular dimensions, or with a graduated cylinder filled with water if it sinks and has irregular dimensions. One milliliter (mL) of water is the same as 1 cm^3, so you can easily convert between them.

Measure and record the volume of the two cubes that you used in your initial ideas. Show your work.

Now measure the volume of a small piece of rock (use one of the three varieties on the supply table). Brainstorm the best way to do this with your group, and then record below the method you came up with. Go ahead and measure the volume, and please be sure to include units.

On your own, how would you describe the difference between the two cubes in the initial ideas? Be as specific as you can.

STEP 3

Take a marshmallow and roll it firmly between your palms as much as you can without removing any material from it. Has the volume changed? How has it changed?

Is there another property of the marshmallow that has changed?

DENSITY

We call the inter-relationship of an object's mass and its volume its **density**. Every material has a mass that can be weighed and a volume of space that it occupies. However, the relationship between a material's mass and volume tends to vary from one kind of material to another. For example, a bucket of rocks has a much greater mass than an equal-sized bucket of air. Therefore, a useful way to describe an object is to determine its mass per unit of volume, called **density**. Per refers to division, as in miles per hour (distance divided by time). So density is the measure of an object's mass divided by its volume (density = mass/volume). Scientists and mathematicians use the Greek character rho (ρ) to represent density. Also, as the gram (g) is the basic metric unit of mass, and the cubic centimeter is the basic unit of metric volume (cm^3), so density (ρ) is usually expressed in grams per cubic centimeter (g/cm^3).

Now let's go back to the modeling clay that you used in your initial ideas. When you break off a piece and put it in water, does it sink or float? What about the smaller piece: does it sink or float?

Do you predict that you could ever get the clay to float by breaking off a smaller and smaller piece? Why or why not?

Now go back and determine the density of each of the two cubes from the initial ideas. Is the density of each cube the same or different? How do you know?

STEP 4

Explain how you could use a graduated cylinder and a gram balance to determine the density of water (ρ_{water}) in g/cm^3. Return to the Volume section of step 2 to remind yourself of how to determine the volume of water.

Now use your procedures to calculate the density of water as precisely as you can. Show your data and

SUMMARIZING QUESTIONS

1. If you have two objects of the same volume, but one weighs more than the other, which has a greater density? What is your evidence?

2. If you have two objects of the same weight, but one is larger (greater volume) than the other, which one has a greater density? What is your evidence?

3. a. Look at one of your cubes from the initial ideas. If you cut it in half and take one half away, has the mass changed? If so, by how much?

   b. Has the volume changed? If so, by how much?

   c. Has the density changed? How do you know?

   d. Would the density change if you cut it into quarters? Eighths? Sixteenths? Why or why not?

4. Would the density change if you cut it into unequal pieces? Why or why not?

5. Explain why the tiny piece of clay sinks just like the larger piece.

6. In your own words, how would you describe density (don't just say mass divided by volume!)?

In your group, discuss your answers to these questions. Summarize and illustrate your answers on a whiteboard and be prepared to discuss them with the rest of the class. Write down any changes in your ideas below.

ACTIVITY 2 *Density, Gravity and Motionless Balanced Floating (Isostasy)*

PURPOSE

In this activity we will get our first look at why understanding density is so important for understanding Earth processes. Floating wood blocks in water may seem like an odd place to start, but it is our best analogy for understanding processes as diverse as how icebergs float in water and how the Earth's crust "floats" on its solid (but flowing) mantle.

Q. How can we relate the density of an object to how high it floats in a fluid?

INITIAL IDEAS - ON YOUR OWN

You have probably heard or seen pictures of icebergs floating in the ocean. On your own, why do you think icebergs float? Be sure to include density in your answer.

You've also probably heard the expression the "tip of the iceberg." Why do you think that more of an iceberg sits below the surface of the ocean (the water line) than above it?

✓ **CHECK WITH YOUR INSTRUCTOR: In your group, discuss your answers to the questions above. Add to your previous answer if you need to in the space below. Share your group's answer with the class.**

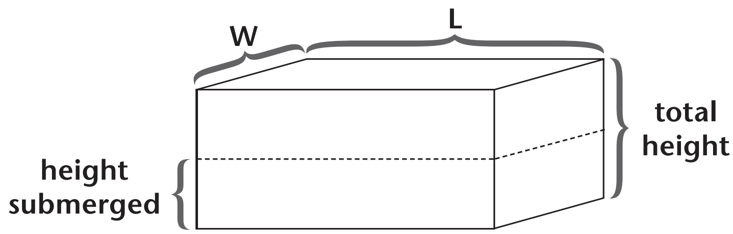
EXPERIMENT 1 *How does the density of an object affect how high it will float in a fluid?*

COLLECTING AND INTERPRETING EVIDENCE

- one transparency of Table 3-1 (for the whole class)

YOUR GROUP WILL NEED

- 1 labeled wood block (about 8 cm x 10 cm x 4 cm)
- small bucket to float wood block
- water
- gram balance (1g accuracy)
- ruler
- calculator
- grease pencil



STEP 1

Obtain one (or two) of the wood blocks provided at the supply table.

1. Measure the height, length, and width of your block (in centimeters), then calculate the block volume:

   Height ____ cm x Width ____ cm x Length ____ cm = Volume _____ cm^3

2. Weigh the wood block (in grams), then calculate the block density:

   $$\frac{\text{Mass \_\_\_\_ g}}{\text{Volume \_\_\_\_ cm}^3} = \text{Density \_\_\_\_ g/cm}^3$$

There is a lot of confusion about how much stuff and how big the stuff is when we use the scientific term density. An example of this problem is shown in this question:

"Sara reports that she has a second block of this same kind of wood that was three times as large as the one you had. What does she mean? Does this mean three times the volume? Or three times the mass? Or does it mean: Each side is three times as long?"

YOU CANNOT TELL! That is the problem with just referring to big or large or small. When talking about density, we are talking about a fixed or constant ratio of the mass of a chunk of stuff to the volume of that particular chunk of stuff: M:V is always the same ratio.

Using the density of your block of wood, figure out the mass of a chunk of your wood if you had 3 times the volume of your chunk. Take notes on your reasoning. Make sure everyone in your group gets the same answer and you all agree on the reasoning.

Mass = ____________________

Using the density of your wood, figure out (as a group) the volume of a chunk of your wood if you had 5 times the mass as your piece in the lab. Take notes on your reasoning.

Volume = ____________________

3. Return to C3A1 Experiment1, Step 4 for the results you obtained for the density of water ________g/cm³. The scientifically accepted value for the density of water at 4°C is 1 g/cm³. How close were your measurements?

Compare the density of your block to water by expressing the block density (ρ_{water}) as a percentage of water density. Use 1 g/cm³ for water density.

$$\frac{\text{Block density \_\_\_\_ g/cm}^3}{\text{Water density \_\_\_\_ g/cm}^3} \times 100 = \text{\_\_\_\_ Block } \rho \text{ as \% of water } \rho$$

Note: We multiply this fraction by 100 to convert the result into a percentage.

Record all of the above data for your specific block in Table 3-1.

STEP 2

Before proceeding, make a prediction of the percentage of the wood block that will be submerged when it is placed in water. What information did you use to make this prediction?

Float the wood block in a bucket of water, then use the grease pencil to mark the water line on the side of the block. Measure the height of the wood block that was submerged in the water, then calculate the percentage of the wood block that was submerged

$$\frac{\text{Height submerged \_\_\_\_ cm}}{\text{Total height of block \_\_\_\_ cm}} \times 100 = \text{\_\_\_\_ \% Submerged}$$

Fill in your data in Table 2-4 below for your block:

TABLE 3-1

	Height (cm)	Width (cm)	Length (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)	Block ρ as % of Water ρ	Height Sub-merged (cm)	% Submerged
Block 1									
Block 2									
Block 3									
Block 4									
Block 5									
Block 6									
Block 7									
Block 8									

Your instructor will provide a table in the front of the room like the one above. Fill in your group's data on that table, then fill in your classmates' data on the table above.

Finding patterns in this numerical data

Using the graph paper and scale below, plot the % submerged versus the density as a % of water. Scientists avoid looking at any single measurement, understanding that all measurements are the best estimate at the moment of the quantity represented. There is often variability due to lots of things, not the least of which can be attributed to how difficult it is to make those measurements in the first place. One of the more powerful strategies to reveal patterns and to help de-emphasize this variability in individual data, is to graph pairs of related quantities and look for "trends". Typical "trends" can be represented by lines and curves, not by connect the dots on the graph.

Plot the % submerged on the horizontal axis and the density as a % of water on the vertical axis

1. Describe the **general** trend that you observe between how dense the block of wood is compared to how deeply it sinks into the fluid it is floating in.

2. Use one stroke of your pen to draw a single straight line that you think best represents the "trend" in your class data. Do you think this line should go through the (0,0) point? What would that mean?

3. Based on the above data, describe the relationship between the density of a block (as a percentage of water), and the percentage of that block that is submerged in water.

4. If you submerged these same blocks in a liquid that was twice as dense as water (i.e. 2 g/cm^3) how would that change the percentage of the block that would be submerged?

5. If each of these blocks were twice as tall, and then were floated in a bucket of water, how would that change the block submerged height? How would that change the percentage of the block that would be submerged?

6. If each of these blocks were half as tall, and then were floated in a bucket of water, how would that change the block's submerged height? How would that change the percentage of the block that would be submerged?

In your group, discuss the answers to the above questions, and be prepared to discuss your answers to 3-6 with the rest of the class.

SCIENTISTS' IDEAS

Density, Gravity and Isostasy

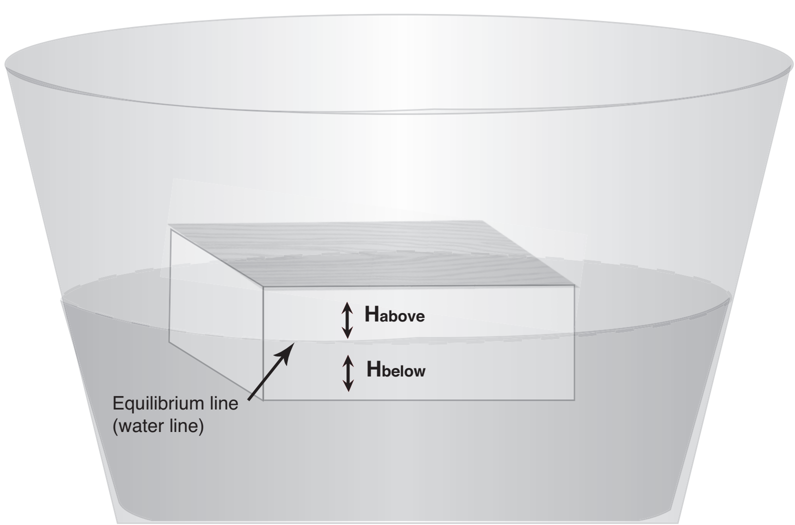
Isostasy is just a fancy word for motionless, balanced floating. As you found in your equation, the height of this floating depends upon the densities of the materials involved.

Scientists have wondered for centuries about how the distribution of Earth materials is related to their density and gravity. For example, Greek scientist and mathematician, Archimedes, experimented with floating objects around 225 B.C. When he placed a block of wood in a bucket of water, he noticed that the block floated and the water level rose (Figure 3-1).

When he pushed down on the wood block, the water level rose even more. And when he removed his fingers from the wood block, the water pushed it back up to its original level of floating. Archimedes eventually realized that every floating object is pulled down (toward Earth's center) by gravity, so the object displaces fluid and causes the fluid level to rise. However, Archimedes also realized that every floating object is also pushed upward by a buoyant force that is equal to the weight of the displaced fluid. This is now called Archimedes' Principle.

An object will sink if it is heavier than the fluid it displaces (is denser than the fluid it displaces). An object will rise if it is lighter than the fluid it displaces (is less dense than the fluid it displaces). But a floating object is balanced between sinking and rising. The object sinks until it displaces a volume of fluid that has the same mass as the entire floating object. For example, if a wood block weighs 200g, it would displace 200g of water. When the object achieves a motionless floating condition, it is balanced between the downward pull of gravity and the upward push of the buoyant force.

FIGURE 3-1



Isostasy

In the 1880s, geologists began to realize the abundant evidence that levels of shoreline along lakes and oceans had changed often throughout geologic time in all parts of the world. Geologists like Edward Suess hypothesized that changes in sea level can occur if the volume of ocean water changes in response to climate. Global atmospheric warming leads to sea level rise caused by melting of glaciers (cryosphere), and global atmospheric cooling leads to a drop in sea level as more of Earth's hydrosphere gets stored in thicker glaciers. However, an American geologist named Clarence Dutton suggested that shorelines can also change if the level of the land changes (and the volume of water remains the same).

Dutton reasoned that if blocks of Earth's crust are supported by fluid materials beneath them, then they must float according to Archimedes' Principle (like wood blocks, icebergs, and boats floating in water). Therefore, he proposed that Earth's crust consists of buoyant blocks of rock that float in gravitational balance on top of the mantle. He called this floating condition isostasy (Greek for "equal standing"). Loading a crustal block (by adding lava flows, sediments, glaciers, water, etc.) will decrease its buoyancy, and the block will sink (like pushing down on a floating wood block). Unloading materials from a crustal block will increase its buoyancy, and the block will rise. Therefore, you can also think of isostasy as the equilibrium (balancing) condition between any floating object (like the wood in Figure 3-1), and the more dense fluid in which it is floating (like the water in Figure 3-1).

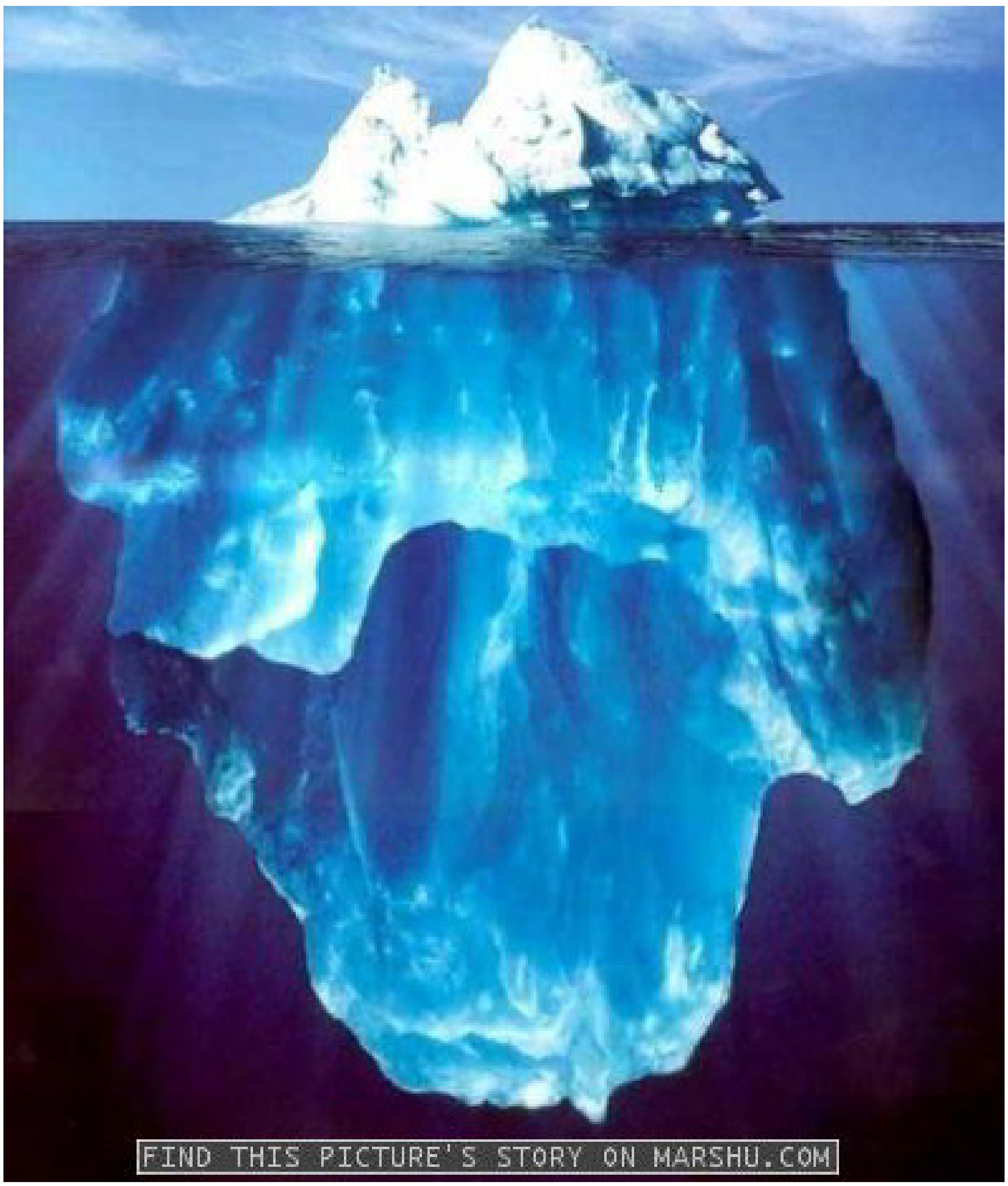
Given that the density of water in ice (in icebergs) is 0.917 g/cm^3 and the average density of (salty) ocean water is 1.025 g/cm^3:

1. What is the density of ice, as a percentage of the density of salty ocean water? What percentage of an iceberg is submerged below water level?

2. Because ocean water temperatures near the poles can be very close to the freezing point of ice, only the portion of the ice that is exposed to the air (above the water level) tends to melt. What will happen as the top of the iceberg melts away?

3. Test your prediction on the iceberg in Figure 3-2. Do the values you calculate in question 1 make sense compared to what you observe? Why or why not? Optional: Use a grid (count boxes) to calculate what proportion of the iceberg is below sea level (the equilibrium line) and what proportion is above sea level to validate your calculations in question 1. (Count all boxes and parts of boxes.)

FIGURE 3-2



Share your answers to these questions with your group.

EXPERIMENT 2 *Isostasy simulator*

On a computer, open up Cycle 3, Act 2, Experiment 2 Simulator. Click on it and then click on "Isostasy Basics". Note that the dimensions are representative of the actual values for the thickness and density of Earth's "blocks" and the density of the material that supports those blocks.

Refer back to your answers to the discussion questions at the end of Experiment 1. Confirm each of your answers by manipulating the block density, fluid density, and block height values on the Isostasy Simulator as follows.

However, before changing any of the values, record the initial block density, fluid density, and block height below. Then, calculate the block density as a percentage of the fluid density, and the percentage of the block that is submerged in the fluid:

Block Density: __________ g/cm^3 Block Height: __________ km Fluid Density: __________ g/cm3

Block Density as a % of Fluid Density: __________ %

% of Block Submerged: __________ %

1. a. When you double the density of the fluid (but leave the block density and block height the same), how does that change the Block Density as a percentage of Fluid Density?

____

____

____

____

   b. How does that change the percentage of the block that is submerged?

____

____

____

____

2. a. Reset to initial settings. When you increase the block density by an extra 50% (but leave the block height and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

   b. How does that change the percentage of the block that is submerged?

3. a. Reset to initial settings. When you double the height of the block (but leave the block density and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

   b. How does that change the height of the block that is submerged?

   c. How does that change the percentage of the block that is submerged?

4. a. Hit reset button to initial settings. When you reduce the height of the block by one-half (but leave the block density and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

   b. How does that change the height of the block that is submerged?

   c. How does that change the percentage of the block that is submerged?

5. How well do your Isostasy Simulator experiments confirm your answers to the discussion questions at the end of Experiment 1?

SUMMARIZING QUESTIONS

1. How does changing the density of a block affect the elevation (H_{above}) of that block floating in a liquid?

2. How does changing the density of the liquid affect the elevation of a block floating in that liquid?

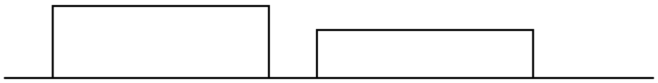
3. How does changing the block height affect the elevation of the block floating in a liquid?

4. Given what you know about isostasy, predict how ice would float in both fresh water and seawater.

5. Optional: You are going to have a party and you want to make "magic" ice cubes that will sink to the bottom of your guests' water. How could you make these magic ice cubes?

6. You have an ice cube floating in a glass of water. Predict what would happen to the total % submerged (and height that is submerged) if you stacked another ice cube directly on top of the first. What is your evidence?

7. You have two blocks where you can only see the top of the blocks floating above the water. One block has higher elevation (height above) than the other.



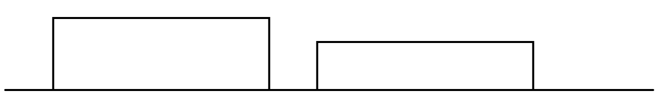
water line

- Could the two blocks have the same density? Explain your reasoning.

- Could the block on the right be less dense than the block on the left? Explain your reasoning.

- If the two blocks have the same total height, which is more dense? How do you know?

8. Now suppose you have the same setup as in Question 7 but you know that the taller block has an elevation (H_{above}) of 10cm, and the shorter block has an elevation (H_{above}) of 5cm. Both blocks are 80% as dense as water. Now draw in the bottom of those blocks.



water line

Discuss your ideas with your group. Have your ideas changed? Write down any changes in your ideas after talking with your group or after the following class discussion.

Check in with your instructor

Use your group's whiteboard to describe in words or pictures this relationship between density ratios, block height, and elevation of a block floating in a liquid. Use evidence from questions 7 and 8 in your answer. Can you relate this back to the iceberg idea?

ACTIVITY 3 *Isostasy and Earth's Global Topography*

PURPOSE

Using what we have learned earlier in this cycle about density and other measurements, we will see that the density of rocks on Earth's surface have a strong effect on the topography of Earth.

Q. How can we relate the density of rocks to the topography of Earth?

INITIAL IDEAS

Once again, look at the 3-D map from the Initial Ideas using 3-D glasses. Write down some large-scale observations about patterns in elevation of Earth's surface (i.e., oceans vs. continents) Make sure you are recording *observations* rather than *inferences*.

In your group, share and discuss these observations about patterns in elevation. List one or two on your whiteboard. Include processes or rock properties discussed in Cycles 2 + 3 that might be responsible for the observations you have made (i.e., what inferences can you make?).

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *How does the density of Earth rocks vary?*

YOU WILL NEED

- gram balance (0.1g accuracy)
- smallest graduated cylinder that a rock will fit in
- water
- small samples of granite, basalt, peridotite rock
- small piece of silly putty

STEP 1

Using the techniques you learned in Activity 1, measure the densities of the two different rock types that make up most of Earth's surface as exactly as you can (to tenths of a g/cm^3).

- **Basalt** is a fine grained, volcanic rock that makes up the floor of the oceans. As with any rock, it is made up of minerals - in this case fine grained crystals of feldspar, pyroxene, olivine and magnetite.
- **Granite** is a coarse-grained rock that makes up much of the contingents. It is commonly made up of coarse-grained crystals of feldspar, quartz, biotite, and hornblende.

Finally, measure the density of **peridotite**, the rock that makes up most of the deep interior of Earth (Earth's mantle) beneath the continental and oceanic rock.

- **Peridotite** is a coarse-grained rock that contains a higher percentage of a mineral called olivine plus pyroxene and garnet.

Briefly describe how you made your measurements on each item below:

• Sample granite (continents): ______________ g/cm^3 How determined?

____

____

____

____

• Sample basalt (ocean floors): ______________ g/cm^3

____

____

____

____

• Sample peridotite (mantle): ______________ g/cm^3

____

____

____

Write down your group's results for granite, basalt, and peridotite in the density chart below (Table 3-2) and on the table on the board provided by your instructor. Compare your results with those of your classmates.

TABLE 3-2 **DENSITY CHART**

GRANITE

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm^3)	SAMPLE DENSITY (g/cm^3)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide **Average**			**2.8**

BASALT

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm^3)	SAMPLE DENSITY (g/cm^3)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide Average			3.1

PERIDOTITE

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm^3)	SAMPLE DENSITY (g/cm^3)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide Average			**3.3**

Are all the measurements exactly the same? Are they similar? Why or why not?

Do you think averaging the data is a good idea? Why or why not?

How do they relate to the worldwide average? If they are different, why might that be?

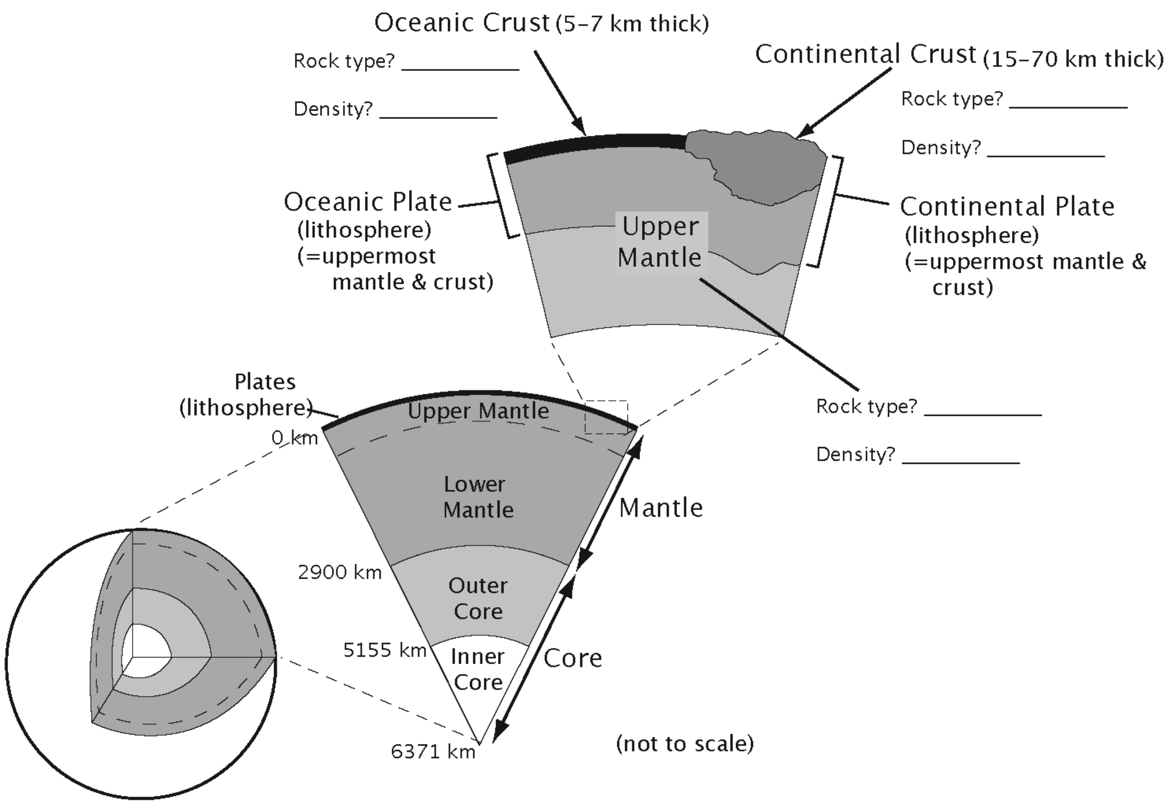
OPTIONAL: Discuss the answers to these questions in your group and be prepared to share your ideas with the class.

SCIENTISTS' IDEAS

Granite and Basalt and the Inside of Earth

If you think of *Earth's crust* (the outermost layer) simply, it is made up of an average of two different rock types. The continental crust (the high land masses) is *Granite* (light-colored coarse-grained intrusive rock) and the ocean crust (beneath the oceans) is made up of *Basalt* (dark-colored fine-grained extrusive rock). This crust rests on the *peridotite* rock of Earth's interior (the mantle) (see Figure 3-3)

FIGURE 3-3



How do we know what is in the mantle of Earth?

Three lines of evidence: seismology (the study of Earth's structure and composition using earthquake waves which you will explore in Cycle 5), mantle xenoliths (pieces of the mantle carried up in lava, such as the samples on display in the room), and lab experiments indicate that the upper part of Earth's mantle is peridotite rock. The peridotite has an average density of about 3.3 g/cm^3 and experiences slow flow when it is at temperatures above 800°C. Seismology also reveals the thicknesses of crust and mantle layers.

GROUP DEMONSTRATION

Have someone in your group obtain a piece of silly putty from the supply table and roll it into a ball. Cut it in half and put the flat side down on a piece of paper. Using a colored pencil, draw the outline of the shape of the silly putty onto the paper.

Fifteen minutes later, return to the silly putty and draw the outline of the shape again with a different color pencil. Now lift up the silly putty. Has the shape changed? Is the silly putty a solid? Did it flow?

You can use this as an analogy to Earth's mantle. A flowing solid.

How might the wood blocks and water also be an analogy to Earth's crust and mantle? Sketch your ideas.

CHECK IN WITH YOUR INSTRUCTOR. HE/SHE MAY SHOW YOU ANOTHER DEMONSTRATION HERE.

WRITE DOWN YOUR THOUGHTS:

Review the 3-D map from the beginning of Cycle 3, Initial Ideas, and Figure 3-3 on previous page. Consider what role density might be playing in the height of Earth's surface. Could differences among the three rock types that make up continents (granite), ocean basins (basalt) and mantle (peridotite) be responsible for Earth's distinct high and low topography? If so, how?

Share these thoughts with your group. OPTIONAL: Draw your group's answer on your whiteboard.

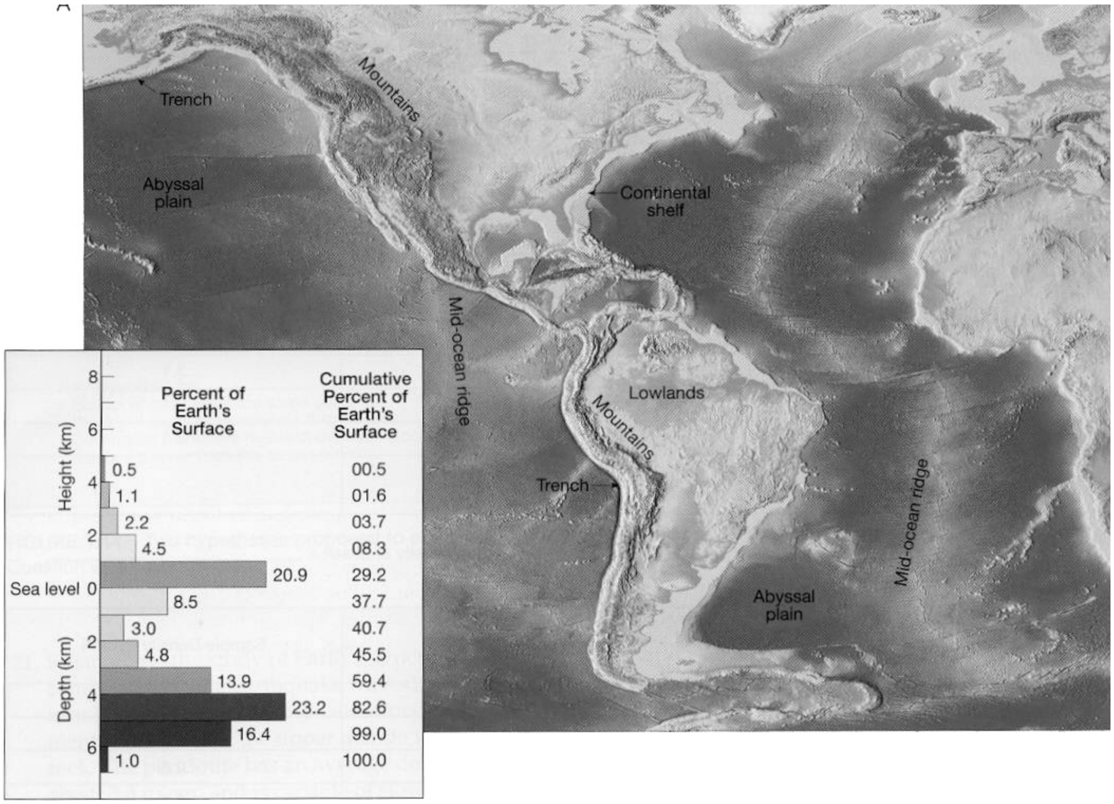
FIGURE 3-4. GLOBAL TOPOGRAPHY OF EARTH

A. Portion of Earth with ocean removed, based on satelite-based radar and laser technologies.

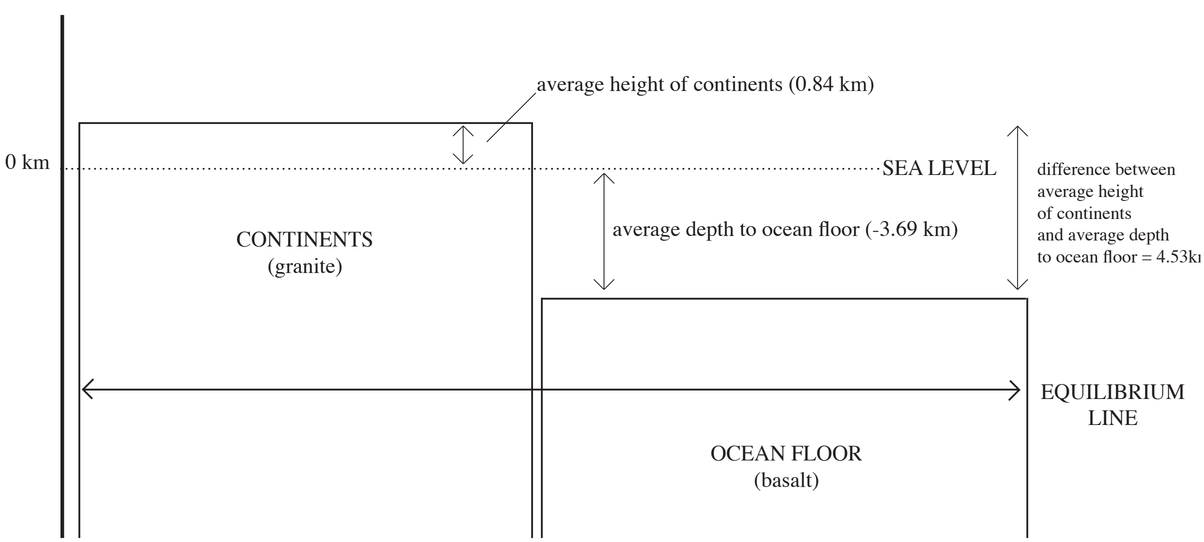
B. Histogram of global topography.*

C. Average height of continents (granite) compared to average height of ocean floor (basalt).

A.



C.



SUMMARIZING QUESTIONS

1. Seismology indicates that the average thickness of basaltic oceanic crust is about 5.0 kilometers. Use the average density of basalt (3.1 g/cm3) and an average density of peridotite (3.3 g/cm^3) to determine how high basalt 'floats' in the mantle.

   To do this, apply the same technique used in Activity 2 to determine the density of the ocean crust 'block' as a percentage of the peridotite mantle 'fluid', and the percentage of the oceanic block that would be submerged. In this case, though, we want to know how much of the block is **not** submerged (H_{above}) (e.g. if 75% of the block is submerged, then the remainder of the block, 25%, 'floats' above the mantle. Then if the block height is 10 kilometers, then 2.5 kilometers will 'float' above the mantle.)

   Note: recall our recent group demonstration, where we saw that silly putty flows over a period of time. A portion of the upper mantle behaves in a similar manner, allowing the continental blocks to float at different levels, depending on block height and block density. *Show your calculations and sketch a block of basalt floating in peridotite.*

2. Seismology indicates that the average thickness of granitic continental crust is about 30.0 km. Do the same kind of analysis as in the previous question. Use the average density of granite (2.8 g/cm^3), the average density of peridotite (3.3 g/cm^3) to determine how high granite 'floats' in the mantle. Calculate the density of the continental crust 'block' as a percentage of the peridotite mantle 'fluid', the percentage of the continental block that would be submerged, the percentage of the continental block that would 'float' above the mantle, and the height of the continental block above the mantle. *Show your calculations and sketch a block of granite floating in peridotite.*

3. What is the difference of the height above (in kilometers) between your answers in 1 and 2?

4. How does this difference between 1 and 2 compare to the actual difference between the average height of continents and the average depth to the ocean floor (Figure 3-4)? Why might they be different/the same?

5. Given what we have done in this cycle, what are the two main reasons that continents are higher than ocean basins? Illustrate your answer and be sure to include the bottoms of both continental rock and oceanic rock in your illustration.

6. Given that mountains are higher than valleys, and they are both made of continental crust, what must the bottom of the continental crust look like beneath these regions? (Hint: remember that all continental crust is made out of pretty much the same stuff.) Be specific about percentages, and explain your reasoning.

Discussion the answer to questions 4 - 6 with your group, and whiteboard your answer to the class.

Write down any new ideas you learned after looking at groups whiteboards.

QUOTE: *"If by some fiat I had to restrict all this writing to a single sentence, this is the one I would choose: The summit of Mt. Everest is marine limestone"* **John McPhee**

CLASS DEMONSTRATION (OR GROUP ACTIVITY)

Your instructor will now lead a discussion on crust thickness and isostasy.

Final reflection: How have your own ideas changed about the concept of density and how density relates to earth topography? How about total height of crustal blocks? Where in the cycle did learning occur for you?

CYCLE 3 HOME WORK SET

The outer portion of Earth (over 80% of Earth's volume) is made up of rocks. As you saw in Cycle 2, rocks are a collection of minerals, which are an assemblage of elements. Silicon (Si) and oxygen (O) are the two most abundant elements within Earth, thus most minerals that form rocks are compounds of those two elements. These are the silicate minerals. Some other elements that are common in rock-forming minerals are iron (Fe), magnesium (Mg), aluminum (Al), calcium (Ca), potassium (K), and sodium (Na).

The density of a mineral is determined by the type of elements (e.g., silicon, oxygen, magnesium etc.) and the packing arrangement of these elements in a mineral. Since rocks are a collection of minerals, the density of the rock is dependent upon the density and proportions of its minerals. In this homework you will get to explore common rock forming minerals, their density and the resultant densities of rocks. You will then use these densities to explore isostasy.

Answer on a separate sheet

1. The mass and volume of three common rock-forming silicate minerals, and magnetite, an iron oxide (a nonsilicate mineral) were measured in a lab. Determine the density of each mineral and list them from highest density to lowest. Show calculations.

	Mass (grams)	**Volume (cm^3)**	**Chemical Formula**
plagioclase feldspar	6.25	2.29	$CaAl_2Si_2O_8$
garnet	3.9	0.93	$Fe^{2+}{}_3Al_2(SiO_4)_3$
potassium feldspar	13.42	5.24	$KAlSi_3O_8$
magnetite	8.81	1.71	$Fe^{2+}Fe^{3+}{}_2O_4$

2. a. What unit is mass measured in? Be sure to show units. Explain your reasoning.

   b. What is the mass of a 1 cm^3 cube of each mineral? Be sure to show units. Explain your reasoning.

   c. What is the density of half of a 1 cm^3 cube of magnetite? Explain your reasoning.

   d. What is the density of two, 1 cm^3 cubes of garnet? Explain your reasoning.

Listed below are the average densities of some common rock forming silicate minerals and magnetite (http://webmineral.com/Alphabetical_Listing.shtml).

Mineral	**Density (g/cm^3)**	**Chemical Formula**
potassium feldspar	2.56	$KAlSi_3O8$
plagioclase feldspar	2.73	$CaAl_2Si_2O_8$
pyroxene	3.40	$Ca(Fe,Mg)Si_2O_6$
olivine	3.32	$(Mg,Fe)_2SiO_4$
garnet	4.19	$(Fe,Mg_{)3}Al_2(SiO_4)_3$
hornblende	3.20	$Ca_{2[}Mg_4(Al,Fe)]Si_7AlO_{22}(OH)_2$
muscovite	2.82	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
biotite	3.09	$K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$
magnetite	5.15	Fe_3O_4
quartz	2.62	SiO_2

3. A rock type that typifies the continental crust is granite. Granites have an assortment of silicate minerals that have higher percentages of potassium than other minerals. For example, one type of granite may have 65% potassium feldspar, 15% quartz, 15% biotite and 5% hornblende. Determine the density of this granite based on its mineral assemblage. You will need to do a weighted average to answer this.

4. If magma of the same element makeup as granite spills out onto the surface of Earth, the minerals would be microscopic in size because it cools rapidly as an extrusive rock. Even though the extrusive rock would have the same element makeup—it is given a different name (rhyolite) because it formed on Earth's surface. Does a microscopic piece of quartz in a rhyolite have the same density as a pea-sized piece of quartz in granite? Explain (assume nothing else is different about the quartz in the two rocks except for their size).

5. As you will see in Activity 3, Experiment 1, basalt is another very common rock that is specific to the crust on the ocean floor. Basalts contain a collection of minerals that are different than those in granites because the element makeup of a basaltic magma is different. Basalts contain heavier silicate minerals rich in elements like magnesium, iron, aluminum and calcium. A typical ocean crust basalt may contain 50% plagioclase feldspar, 45% pyroxene, 4% olivine and 1% magnetite. Determine the average density of this basalt based on its mineral assemblage.

6. Deeper in Earth, in the mantle below the continental and ocean crusts (see Activity 4 Scientists Ideas), is another type of rock called peridotite. Peridotite contains a high percentage of a mineral called olivine plus other silicate minerals that are rich in magnesium and some iron. Determine the average density of a peridotite that contains 80% olivine, 18% pyroxene, and 2% garnet.

7. Would any ten minerals in the table above float in water? Explain.

8. There is a special heavy liquid called LST that has a density of 2.85 g/cm^3 . LST is used to separate minerals having different densities. Which of the 10 minerals listed in the table would sink, and which minerals above would float in a bath of LST? What would happen to the muscovite? Explain your reasoning.

9. Extending what you did in Activity 3, if you placed a cube of quartz having side lengths of 1.0 cm in a bath of LST, and then rested a cube of potassium feldspar with the same dimensions on top of the quartz cube, what percentage of the total height would be below the equilibrium line? What would be the height below the equilibrium line? What percentage would be above the equilibrium line? What would be the height above the equilibrium line? What is the volume of each of those cubes?

10. Use the two-cube problem above to explain isostatic rebound, i.e., explain what would happen to the quartz cube after removing the potassium feldspar cube. Calculate the height above the equilibrium line for the remaining cube of quartz. How does this compare to how much quartz was above the equilibrium line when there was a potassium feldspar crystal above it?

11. The rebound of the quartz cube in problem #10 would be instantaneous. Isostatic rebound also occurs on Earth's surface, but at a much slower rate and a much larger spatial scale. A depressed continent takes well in excess of 10,000 years to reach a new equilibrium following glacier ice loading and removal. If the Puget Sound region of North America was depressed as much as 200 m during the last glaciation (about 10,000 years ago), determine the average rebound rate in cm/year if all of the rebound occurred in 10,000 years. Note that in reality, the uplift rate is not constant, it is fast in the beginning and slower near the end. For example half the rebound may occur in the first few thousand years.

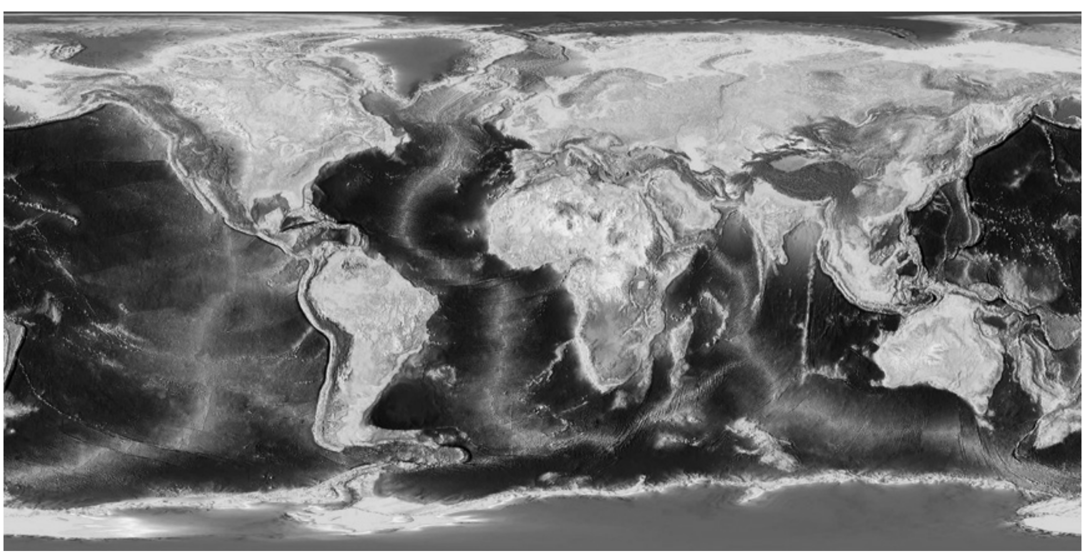
12. A variation of the heavy liquid LST has a density equivalent to a peridotite (3.3 g/cm^3). Float a 1.0 cm^3 cube of granite (2.8 g/cm^3) and a 1.0 cm^3 cube of basalt (3.1 g/cm^3) in the heavy liquid. What percentage of each cube is above the equilibrium line? What is the difference in height above the equilibrium line between the two cubes? Draw your result.

13. Repeat problem #12 with blocks of basalt and granite that are 100 cm x 100 cm wide and 100 cm high.

14. Repeat problem #12 with a block of basalt that is 5.0 km high and a block of granite that is 30 km high (assume an extremely huge bath of LST).

CYCLE 4

How do we know about Earth's tectonic plates?



CYCLE 4

How do we know about Earth's tectonic plates?

ACTIVITY 1 *Discovering Plate Boundaries*

In Cycle 2 you developed skills for observing Earth. In Cycle 3 you developed ideas about how materials behave based on their physical properties such as density and size. You also learned how a jigsaw learning technique works, and you leaned about different rock types and how they relate in the rock cycle. In this activity you will again use a jigsaw structure to observe occurrences and patterns of different features on Earth's surface that provide evidence for the transfer of energy from Earth's interior to Earth's surface. We will investigate how the global topography, different ages of the sea floor rock, and the global distribution of volcanoes and earthquakes help us figure out different types of plate boundaries, and how those plate boundaries accommodate motion of plates over long periods of time.

Q. *What visible features on Earth's surface provide evidence for energy transfers from within the Earth? Where do these features occur? Are they distributed randomly over Earth's surface or do they occur in discernible patterns?*

What will you discover?

1. The locations of Earth's tectonic plates and their boundaries.
2. What happens at plate boundaries.
3. How earth scientists classify plate boundaries.
4. Why it is important to examine plate boundaries when discussing the transfer of energy and matter in Earth Systems.

Activity adapted from: Dale Sawyer, Rice University
http://www.geophysics.rice.edu/plateboundary/home

IN YOUR HOME GROUP

Meet your home group members and work through Initial Ideas. A formal introduction to Activity 1 will take place after the completion of Initial Ideas.

INITIAL IDEAS

Using the skills of OBSERVATION learned in Cycles 1 and 2, look at the 3-D bathymetric/ topographic map of Earth. Review and answer the following questions about Earth:

Where are the highest areas on Earth?

Now describe the locations for mountain ranges. Are they in the interior of continents? Near the edges? Are there mountain ranges in the oceans? If so, describe their shape. (Mountain ranges are portions of the Earth that project well above its surroundings, such as a series of ridges that are alike in form, direction, and origin.)

Are the locations of the features that you identified random or do they occur in some kind of pattern? Describe the pattern(s), if any.

Are you familar with the term "plate tectonics" and Earth's plates? If so, explain briefly below. Define any terms you already know.

Share your thoughts with your group and prepare a white board that illustrates any pattern you come up with.

COLLECTING AND INTERPRETING EVIDENCE

We will take a closer look at pieces of Earth's surface, which we call "plates," large rigid blocks of the Earth's surface.

DISCOVERING PLATE BOUNDARIES JIGSAW DIRECTIONS

To investigate the nature of plate boundaries, we will complete a jigsaw, a cooperative learning strategy that incorporates peer teaching.

- Your "home group" that consists of 4 members will become your Plate Group.
- Your Plate Group will be assigned a specific plate name when you reach Part 4, Step 8.
- Within each Plate Group, each member will be assigned to be part of a Scientific Specialty Group. In this group, each member will master a portion of the information and then return back and share it with the rest of their Plate Group.

The information shared by each representative of a Scientific Specialty Group is a critical link in developing our understanding of plate boundaries, just as each piece is essential to completing a jigsaw puzzle.

- **Cooperative expectation —** all group members will participate fairly and equally in all discussions. Everyone should get a turn to speak. Make sure that each group member can summarize the group discussion.
- **Individual accountability expectation —** each group member learns their part well to teach to their home group. Individual accountability includes **listening skills** and asking clarifying questions.

You have been (or will be) assigned to one of four Scientific Specialties and to one Plate Group.

The Scientific Specialties are:

A. Seismology – the study of earthquakes (using data from a world-wide network of seismometers)
B. Volcanology – the study of volcanoes
C. Geography – the study of topography (using data from ground-based, ship-based and satellite-based surveying)
D. Geochronology – the study of rock ages, in this specific study, the ages of the rocks of the sea floor (using data from magnetism of ocean floor and radiometric dating methods on samples retrieved by drilling in the ocean crust)

The Plates or Plate Groupings are: (these will be assigned to you later)

1. North American Plate
2. Pacific Plate
3. Indian Plate
4. African Plate
5. South American Plate
6. Eurasian Plate
7. Cocos/Nazca/Caribbean Plates
8. Australian Plate
9. Antarctic Plate
10. Arabian Plate

PART 1 *In your home group — your Plate Group* (10 minutes)

OVERVIEW

Become familiar with your role in the jigsaw, and what you will be finding out. Review these questions for which you will be collecting evidence during this project. Do not answer them here

1. How is the surface of Earth segmented into plates?
2. What happens at plate boundaries?
3. What evidence would you look for to determine what kind of plate boundary is present?
4. How do Earth Scientists classify plate boundaries?
5. Why would you examine plate boundaries when discussing the transfer of energy and matter in Earth Systems?

Each group member will be assigned (or volunteer) to become an expert in one of the Scientific Specialties: seismology, volcanology, geography, geochronology. Make sure that each group member knows their individual responsibility in learning their part to share back with your home group.

PART 2 *Preparation for your Scientific Specialty Groups* (10 minutes)

YOU WILL NEED

- one class set of the 4 large Scientific Specialty Maps (3'x3')
- one class Globe
- for each specialist, small color versions of the 4 Scientific Specialty Maps (11"x17", 8$^{1/2}$"x11")
- overhead transparencies of the Plate Boundary Map and the color specialty maps
- for each Plate Group, a set of overhead transparency pens, 4-5 colors, and colored pencils

STEP 2. OBSERVATION (ON YOUR OWN)- Your instructor will hand out 11"x17" maps to each specialist

Recall Cycle 1 and remember the difference between an **observation** and an **inference**. Look at your group's Scientific Specialty map for the ENTIRE WORLD and think about what you see. Be sure that you know and understand what is represented by the colors on your map (look for the Key/legend). You are going to start by observing and describing data on your own then reassemble in your specialist group for a discussion of the data.

First, concentrate your observations to reflect how the data are distributed around the entire world. **OBSERVE the patterns.** Use describing words in your observations such as high or low, deep or shallow, wide or narrow, straight or curved, symmetric or asymmetric, ridge or valley, etc. Specifically make mention of the position of the data relative to land (on a continent or island) or on the ocean floor. Your instructor may give you a sheet with guidelines for these observations.

Do you observe any patterns from your data? At this stage, **do not** make inferences about what any patterns mean. Do not jump to conclusions about the scientific terms used to describe the boundary types. **OBSERVE!** Save inferences for later!

Write down at least six observations (your own!) that describe patterns in your data for the whole world. Describe them thoroughly, as you will be the expert and will teach this information to your Plate Group.

1. __________

2. __________

3. __________

4. __________

5. ______________________________

____

6. ______________________________

____

PART 3 *Assemble in your Specific Specialty Groups* (30 minutes)

STEP 1 - SPECIALTY GROUP DISCUSSION

Compare and discuss your observations with your specialty group members and make sure everyone has a chance to say something. Have other members of the group described patterns of data similar to yours? Remember, do not make inferences at this stage. Determine the six most common observations your group members made and summarize them in Table 4-1.

For now, leave the other columns blank. When you meet in your plate groups, the specialists for the other Scientific Specialty data sets will explain their observations for you.

After you fill in your specialty in Table 4-1, you must consult with your instructor.

TABLE 4-1 **OBSERVATIONS OF SCIENTIFIC SPECIALTY DATA FOR THE WORLD**

GEOGRAPHY OBSERVATIONS	VOLCANOLOGY OBSERVATIONS

SEISMOLOGY OBSERVATIONS	GEOCHRONOLOGY OBSERVATIONS

CHECK POINT 1: After your group has completed Step 1, share your specialty group observations of the Scientific Specialty data with your instructor and he/she will confirm you are ready to move on to Step 2.

STEP 2. PATTERNS IN PLATE BOUNDARY MAP (STAY IN YOUR SPECIALTY GROUP)

YOU WILL NEED

- two copies of paper plate boundary map per student $8^{1/2}$″x11″

Look at your small Plate Boundary Map. This map shows how scientists have devised plate boundaries, the edges of plates. On your small Plate Boundary Map, find the crooked line, the plate boundary, that divides the Atlantic Ocean. Trace a small segment of it with your finger. Now look at your Scientific Speciality Map and find the same place. Observe the data that matches with that segment. Depending on the data that you collected, consider examples of questions below. You might come up with others.

Look at your small Plate Boundary Map. This map shows how scientists have devised plate boundaries, the edges of plates. On your small Plate Boundary Map, find the crooked line, the plate boundary, that divides the Atlantic Ocean. Trace a small segment of it with your finger. Now look at your Scientific Speciality Map and find the same place. Observe the data that matches with that segment. Depending on the data that you collected, consider examples of questions below. You might come up with others.

- Is the topography high or low as compared to the surrounding area?
- Are ages of ocean floor rocks symmetric or asymmetric?
- Is the data set confined to a narrow line or spread out in a wide zone?
- Is the data closely spaced or widely spaced?
- Is the data set a straight or curved line?
- Is the data set right on top of the plate boundary or offset (to the side) from the plate boundary?

STEP 3. GROUP DISCUSSION, MATCHING PLATE BOUNDARIES WITH SCIENTIFIC DATA

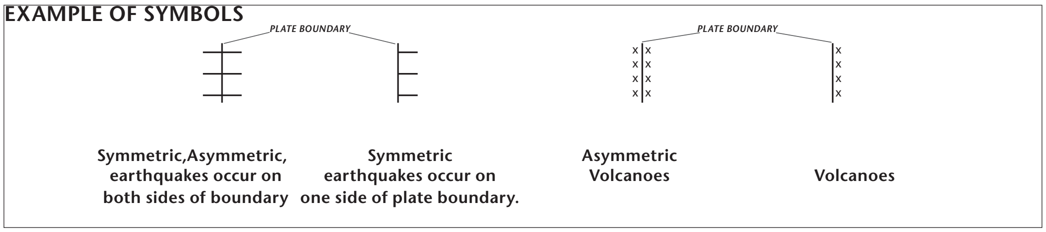
As you just did for the Atlantic Ocean, follow all the plate boundaries and look for patterns in your specialty data. You will see that different segments of plate boundaries have different data patterns. Mark those segments on your small paper plate boundary map with colored pencils. In the next step, you will recognize two to four different "types" of plate boundaries based on these data patterns.

STEP 4. DRAW AND DEFINE PLATE BOUNDARY TYPES

In Step 3 you searched for patterns between the data and plate boundaries. Now you are going to label and define your two to four plate boundary types.

A. Find plate boundaries that show the same pattern of data and call it a "type". Most of the patterns you identify ought to occur in more than one location on the data map. There should be two to four types.

B. Create a symbol for each plate boundary type in your classification scheme. Each symbol should have its own color and shape. If the data is asymmetric with respect to the plate boundary, devise a symbol that reflects that pattern. Use the symbols below as a guide to create your symbols so thta the whole class will have similra symbols.



C. Create a key that includes the symbol and a detailed description/definition of each boundary type.

EXAMPLE OF A KEY FOR A VOLCANO SPECIALTY MAP

PLATE BOUNDARY TYPES FOR VOLCANOLOGY

SYMBOL	DESCRIPTION
	**TYPE 1 BOUNDARY: the line is the plate boundary and the X's locate a line of volcanoes that are asymmetric (off to one side) to the plate boundary.**

D. On your original Plate Boundary Map, for each plate boundary type, color the plate boundaries using the designated color and symbol.

STEP 5. PLATE BOUNDARY TYPES FOR YOUR SCIENTIFIC SPECIALTY GROUP

Summarize and record your plate boundary types for your specialty by filling in Table 4-2. Leave the other columns blank until you meet up in your Plate Groups. In the next step you will reassemble in your Plate Group and the members will teach to you the plate boundary types for their scientific specialty and you will enter their data in the appropriate columns.

✓ **CHECK POINT 2: Check in with your instructor**

TABLE 4-2 PLATE BOUNDARY TYPES BASED ON SCIENTIFIC SPECIALTY

Each Plate Group should have a seismologist, volcanologist, geochronologist, and geographer.

GEOGRAPHY PLATE BOUNDARY TYPES	VOLCANOLOGY PLATE BOUNDARY TYPES

SEISMOLOGY PLATE BOUNDARY TYPES	GEOCHRONOLOGY PLATE BOUNDARY TYPES

PART 4 *Assemble in your Home Groups* (60 minutes)

STEP 6. SHARING OBSERVED SCIENTIFIC SPECIALTY DATA (SHARE TABLE 4-1)

Using the large Scientific Specialty maps or the small one provided for your group, each group member describes the observations and patterns found in their data. Learn about each scientific specialty for the Earth. For this step give an overview of your specialty group's observations and patterns found in the data. Assist your group members in recording the observations for each specialty in Table 4-1. You must have complete information for each scientific specialty from which you will build your global plate boundary classification scheme.

STEP 7. DESCRIBE PLATE BOUNDARY TYPES

Using your personal plate boundary map, each group member gives a brief description about the plate boundary types as determined by your Scientific Specialty Group. Each group member writes the associated information in Table 4-2. IMPORTANT: AS EACH PERSON SHARES, EVERYONE ELSE SHOULD NOTE HOW THE PLATE BOUNDARY TYPES FOR A GIVEN SEGMENT OF A BOUNDARY COMPARES TO THEIR OWN BOUNDARY TYPE FOR THAT SEGMENT.

STEP 8. ASSIGN A PLATE CLASSIFICATION SCHEME FOR YOUR PLATE

Each Home Group will now be assigned a specific plate name and officially become a Plate Group.

Each Plate Group will create a new plate boundary classification scheme that incorporates all of the scientific data sets. Follow the three steps below. Each student will need a new 8-1/2"x11" plate boundary map

1. Identify all the plate boundary lines that determine the perimeter of your plate.
2. Choose a segment of the boundary and see how all the specialty data sets match up. Use the overhead transparencies for each Scientific Specialty to see how they line up.
3. Create a <u>new</u> plate boundary scheme based on the combination of all the data sets. This scheme will be based only on the boundary of your plate.
4. On a new Plate boundary Map, mark the boundaries of your plate using your new color symbol scheme. If a boundary is asymmetric, be sure to devise a symbol that represents that asymmetry.

STEP 9. PROBE YOUR UNDERSTANDING

Consult all the specialty map as you answer the following question:
The map below has been labeled with plate boundary types A, C, and X.
Terri, Scott, and Ben were discussing the plate boundary labeled X (an east-west boundary).

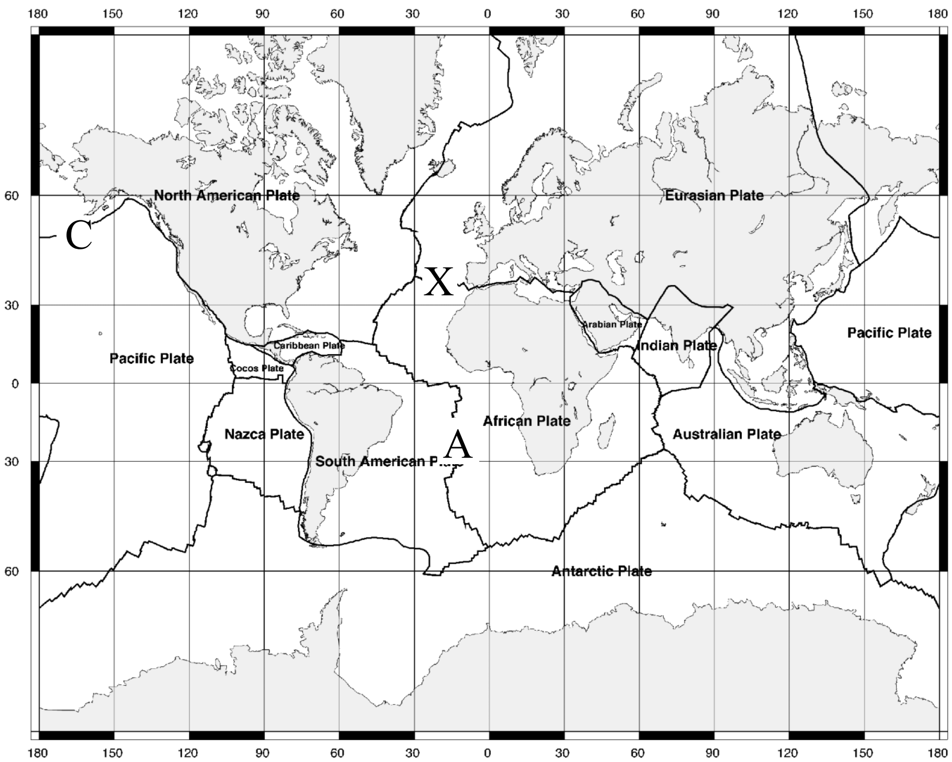


PLATE BOUNDARY MAP
This map is from Dietmar Mueller, Univ. of Sydney

This map is part of "Discovering Plate Boundaries", a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary.

Ben: I think that boundary type X is the same kind of plate boundary as A because there are few volcanoes and the earthquakes lie right along the plate boundary

Terri: I think that X is a different boundary type than A because the A boundary lies right along the youngest age rock. Boundary X crosses different ages, so it must be something different, but X doesn't look like other boundaries on the map.

Scott: I agree with Terri, but I think boundary X must be like boundary C because C crosses different ages too.

Who do you agree with? Justify your answer *using evidence from all the specialty map.*

Class Discussion **Whiteboard your group's response and be prepared to share with the class.**

STEP 10. RECORD YOUR CLASSIFICATION SCHEME FOR PLATE BOUNDARY TYPES OF YOUR PLATE.

Use your newly marked plate boundary map and the data from all four Scientific Specialties to write your new classification scheme for your plate. For the Geography description include the crust type on each side of the boundary. If there is a lack of data in an area be sure to note it as it would mean that there are no volcanoes observed there, or no earthquakes have been detected, or there is no age data for that part of the sea floor.

For example: consider the plate boundary segment that divides the ocean basin between Australia and Antarctica. On the table below this combination of data represents a description of this plate boundary.

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE A	Geography	Oceanic crust is on both sides of boundary and is higher than surrounding ocean basin, a long continuous mountain range
	Volcanology	Does not match up with the plate boundary
	Seismology	Earthquakes on or very close to boundary in narrow zone, all occur at shallow depth
	Geochronology	The youngest sea floor (0 million years) is right at boundary and age increases away from boundary in a symmetrical pattern

Use the charts on the following pages to create a key for your plate's new classification scheme based on the compilation of the data from the four Scientific Specialties. The number of plate boundary types is up to your group, do whatever it takes to describe all the significant boundaries that surround your plate.

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE A	Geography	
	Volcanology	
	Seismology	
	Geochronology	

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE B	Geography	
	Volcanology	
	Seismology	
	Geochronology	

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE C	Geography	
	Volcanology	
	Seismology	
	Geochronology	

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE D	Geography	
	Volcanology	
	Seismology	
	Geochronology	

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE E	Geography	
	Volcanology	
	Seismology	
	Geochronology	

PLATE BOUNDARY	SCIENTIFIC SPECIALTY	DESCRIPTION
TYPE F	Geography	
	Volcanology	
	Seismology	
	Geochronology	

CHECK POINT 3: Explain your classification schemes to your instructor and then he/she will prepare your group for the next step.

PART 5 *Putting it all together* (60 minutes)

STEP 11

CLASS PRESENTATION AND DISCUSSION: DESCRIBING YOUR PLATE

Each group will share with the class their classification scheme for TWO plate boundary types for THEIR assigned plate as assigned by the instructor. *The goal of this share-out is to narrow down the total number of plate boundary types to a few common ones that each group shares.*

1. Your group will use the overhead transparency, projected on the screen, AND a whiteboard or chart paper, to explain to the class the following information about TWO of your plate boundary types that has a good variety of data:
   - Plate name
   - Interesting observations from the different Scientific Specialty areas for that one boundary. Systematically describe the patterns in the scientific data for that boundary type.
   - Description of what occurs on each side of the boundary (using whiteboard or chart paper as necessary)

2. As students in the class listen to each group's presentation, they will compare their plate boundary types to the presenter's, and decide if they have the same boundary type.

3. Repeat for each group.

STEP 12

With each successive group's presentation, your instructor will help the class compare the classification schemes for the plate boundary types as determined by each Plate Group and identify similarities between them.

Your group will plot common boundary types (using a common symbol) on the class poster or class transparency of boundary types.

RECORD THE WORLDWIDE CLASSIFICATION SCHEME

When the class has agreed on a *Worldwide Classification Scheme*, use the charts below to record the new classification scheme.

WORLDWIDE PLATE BOUNDARY CLASSIFICATION SCHEME

	PLATE BOUNDARY TYPE A	PLATE BOUNDARY TYPE B	PLATE BOUNDARY TYPE C
SCIENTIFIC SPECIALTY			
Geography			
Volcanology			
Seismology			
Geochronology			

	PLATE BOUNDARY TYPE D	PLATE BOUNDARY TYPE E	PLATE BOUNDARY TYPE F
SCIENTIFIC SPECIALTY			
Geography			
Volcanology			
Seismology			
Geochronology			

PART 6 *Is your plate moving? How do you know?* (30 minutes)

STEP 13
IN YOUR PLATE GROUP, RECORD YOUR INITIAL IDEAS ABOUT PLATE MOTION BY ANSWERING THE QUESTIONS BELOW

You will develop these ideas further in Activity 2, and then work with data collected using the latest technology in Cycle 5.

INITIAL IDEAS ABOUT PLATE MOTION

Using data from your plate only, do you think it's possible to infer plate motion from the data associated with your plate boundaries? Please explain your reasoning.

If your plate is moving, do you think you can infer the direction it is moving? Please explain your reasoning.

If you think that your plate is moving, draw an arrow on your plate (on your Plate Boundary Map) that shows the direction that you think your plate is moving. Explain your thinking.

INITIAL INFERENCES ABOUT PLATE MOTION

On the class overhead transparency of the Plate Boundary Map (or the large class poster) each group that inferred that their plate is moving will draw an arrow that shows the direction they determined their plate is moving. Be prepared to discuss with the class your reasoning for your plate movement arrow.

Everyone should observe the compiled map that shows the plate movements and look for consistencies and inconsistencies. As a class, try to resolve the inconsistencies. When everyone agrees on the plate motion arrows, each plate group should record the arrows on their own plate boundary map. You will use these plate motion arrows for Step 14.

STEP 14
MOTION OF PLATES AT PLATE BOUNDARIES

In your plate groups examine all the motions indicated by the plate movement arrows.

Use these motions to infer the motion direction for each of the two plates at each type of plate boundary. Record your inferences below and draw a pair of arrows at each type of plate boundary to represent each inference.

STEP 15 (OPTIONAL)
RE-THINKING THE PLATE BOUNDARY TYPES

After you have formulated your inferences for plate motions at plate boundaries, reevaluate the class *Worldwide Plate Boundary Classification Scheme* from a plate motion perspective. Can the classification system be simplified (i.e. reduce the number of plate boundary types) if you consider *only* motion of the two plates that occur at a plate boundary? If so write out this new classification system.

SCIENTISTS IDEAS TO BE HANDED OUT AFTER COMPLETION OF STEP 15.

COMPILE INFORMATION FROM SCIENTISTS' IDEAS

Please compile the plate boundary information from Scientists' Ideas on plate boundaries in Table 4-3. Include a cross section (side-view) perspective.

TABLE 4-3 **PLATE BOUNDARY TYPES — COMPILATION OF SCIENTISTS' IDEAS**

PLATE BOUNDARY TYPE SCIENTISTS IDEAS			
Map view sketch (Bird's eye view)			
Cross-section sketch (Side-view extending from Earth's surface down to a few hundred kilometers) Label important features See ** below.			

**List of features that you may observe at a particular type of plate boundary: Earthquakes (describe depth and locations), Volcanoes, Trench, Spreading ridge – new ocean crust, Subduction zone

At which plate boundary type is new plate created? Discuss the process.

At which plate boundary type is old plate "removed" (subducted, recycled)? Discuss the process.

Which scientific data set would you say best marks where the plate boundaries are located for the entire Earth? Explain your reasoning.

Class Discussion

How do Scientists' Ideas for Plate Boundaries compare with your own? What specialty data is characteristic of each boundary type?

SUMMARIZING QUESTIONS

1. What are differences in earthquake patterns that occur at different plate boundaries?

2. How do you know which plate is subducting at a convergent boundary? Describe an example.

3. For the assigned plate you investigated in your Plate Group, were the boundary types as determined by your Plate Group similar or different than the boundary types accepted by scientists? Explain both similarities and differences.

4. Sketch the boundaries of your plate and label the boundary types as defined in Scientists' Ideas (convergent, divergent, or transform).

5. Re-examine your plate on the 3-D bathymetric/topographic map of Earth in the Initial Ideas. What evidence can you now see that these boundaries exist by looking at the 3-D bathymetric/ topographic map?

6. Why would you look at plate boundary locations for evidence for the transfer of energy and matter in Earth Systems? Please be as specific as you can with your answer.

7. If plates did **NOT** move, would you expect to see earthquakes, volcanoes, age progression on the sea floor, or mountains on Earth? Please explain your reasoning.

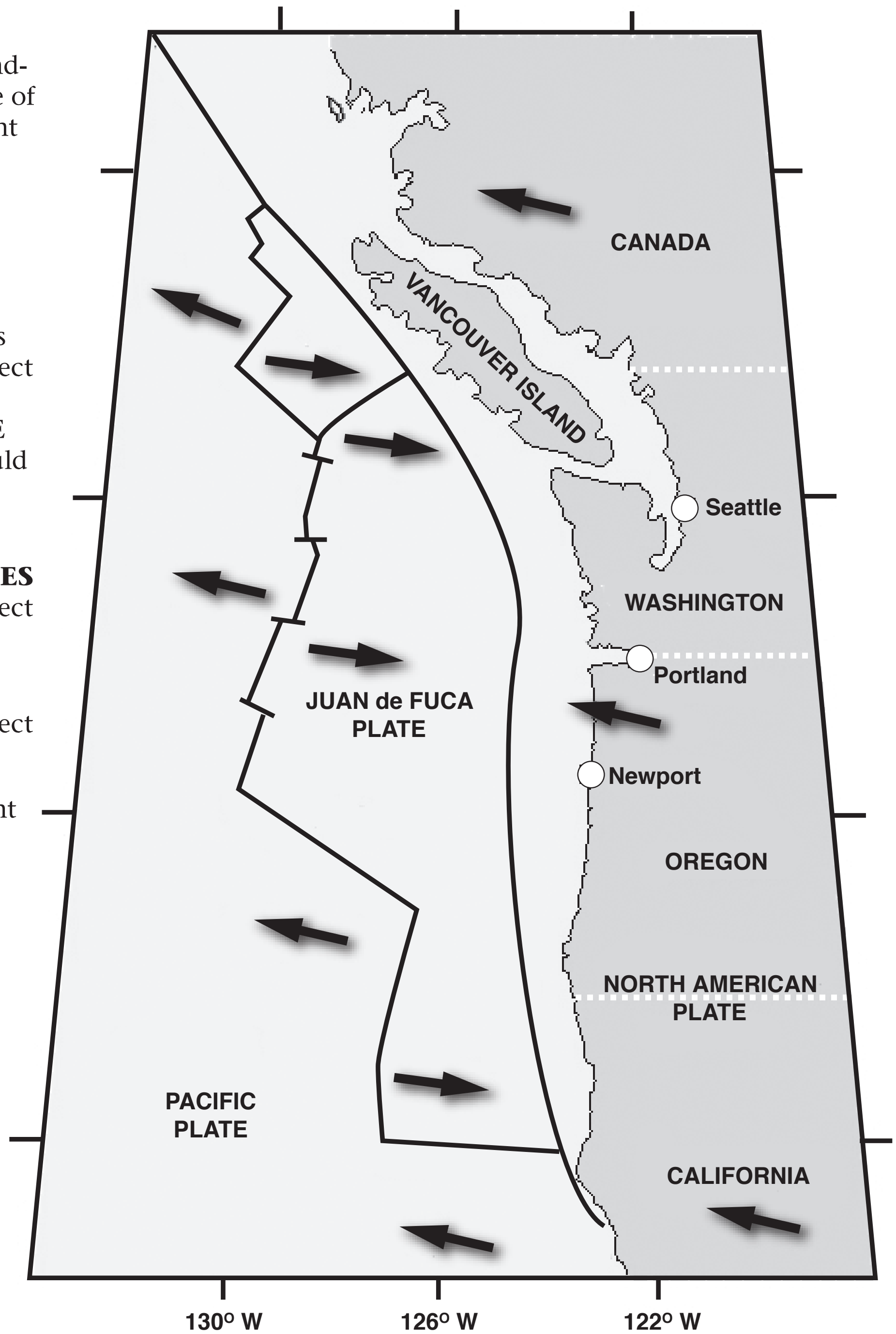
ACTIVITY 1: HOMEWORK

Name ____________________ *Date*____________________

Here is a map of the Pacific Northwest, showing the Pacific Plate, North American Plate and the Juan de Fuca Plate (with associated small plates.) The **heavy black lines** are the boundaries between the plates. The black arrows show the direction of movement of each plate.

INSTRUCTIONS

1. Label each plate boundary line with the type of plate boundary present (i.e. transform, continent-continent convergent, ocean-ocean convergent, etc.)
2. Draw a series of **RED DOTS** at the locations where you would expect shallow earthquakes. Draw a series of **BLUE DOTS** where you would expect deep earthquakes.
3. Draw in **RED CIRCLES** where you would expect to find volcanoes.
4. Draw in **RED LINES** where you would expect to find young rock.
5. Label where you might expect a trench.



ACTIVITY 2 *Plate Movement*

PURPOSE

We have established that plates move and with the help of Scientists' Ideas can now infer the relative motion direction between the two plates by closely examining plate boundaries. In this activity, we will explore how we can determine more precisely what direction and how fast Earth's tectonic plates are moving.

Q. How fast and in which direction are plates moving?

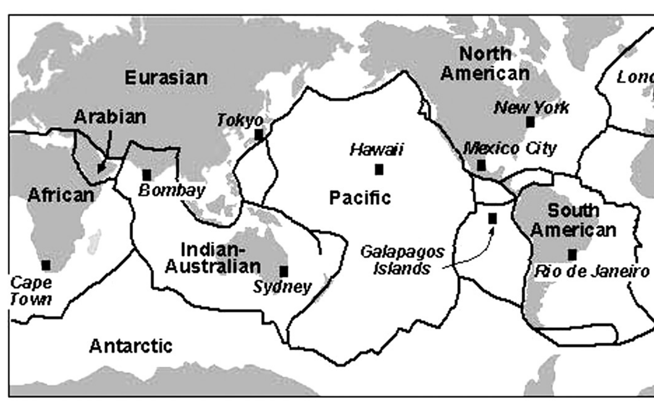
INITIAL IDEAS

What evidence in Activity 1 did you use to infer that plates are moving at all?

How could this evidence be used to calculate the rate of plate movement?

Review the map of plates below. Based on your work in the last activity, predict which pair of locations is moving *closer together* as a result of plate tectonics.

a. Bombay and Sydney
b. Hawaii and Tokyo
c. New York and London
d. Cape Town and Sydney
e. Galapagos Island and Rio de Janeiro
f. Hawaii and Galapagos Island



PART 1 *Investigating Plate Movement using Satellite Data*

YOU WILL NEED

- access to the Internet
- large, laminated plate boundary map for class data collection and discussion.
- GPS Maps
- ruler

Re-assemble your plate groups from Activity 1 (Discovering Plate Boundaries). Go online to NASA's Plate Motion from Space Geodesy site *http://cddis.nasa.gov/926/slrtecto.html*

On the home page of this site scroll down and find an Index Map that shows that the plates and continents of Earth's surface. There are four boxes that enclose specific regions. Click on each of these regions and pick two locations, each on a separate plate. For each of the locations determine the approximate rate of plate movement and record this data on Table 4-4 below. You can determine the approximate rate by using the bar scale at the bottom left corner of each of the regional maps. Compare the length of the red arrow to the length of the bar scale to approximate rate of plate movement.

TABLE 4-4 RATE OF PLATE MOVEMENT

LOCATION	PLATE NAME	COMPASS DIRECTION OF MOVEMENT	RATE OF MOVEMENT centimeters per year (cm/yr)

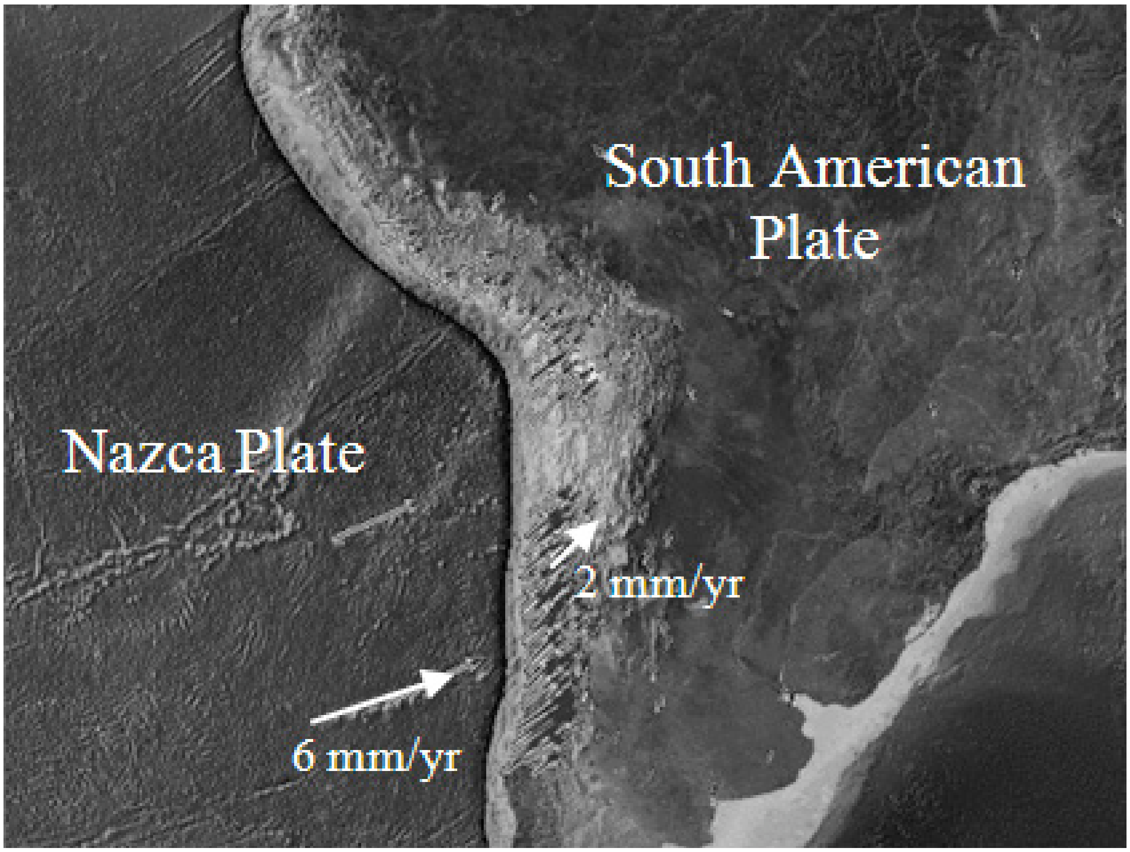
Compare the direction of plate movement arrows to the plate motion arrows you and your classmates drew in Activity 1 (Step 13) by compiling arrows on the large class plate map. Discuss and try to explain any discrepancies (i.e. if the class arrows derived from Activity 1 do not agree with the new Activity 2 data).

You can also view global plate velocities at *http://sideshow.jpl.nasa.gov/mbh/series.html*

For more a more flexible tool for viewing plate motions, see the Jules Verne Voyager, Jr. at *http://jules.unavco.org/VoyagerJr/Earth*. For a more powerful (and thus complicated) tool, see the Jules Verne Voyager at: *http://jules.unavco.org/Voyager/Earth*.

Assessment Probe for Cycle 4, Activity 2 – Plate Movement

Omar, Sue, and René were looking at the map below, which shows the absolute movement for two GPS stations: one station is located on an island in the Pacific on the Nazca Plate and one station in South America on the South American Plate. They disagreed about what the motion data says about the boundary between the two plates.



Omar: I think that the two plates are moving in the same direction, so there can't be any relative motion at their boundary.

René: The Nazca Plate is moving faster than the South American plate, so it must be running into the South American Plate. The boundary must be subduction of some kind.

Sue: The South American Plate is moving away from the Nazca Plate. So I think the boundary must be divergent.

With whom fo you agree? Justify your answer using evidence from any activities in Cycle 4.

PART 2 *Plate Movement in the Pacific Ocean and Western North America Region*

YOU WILL NEED

- access to the internet

Go online to the U.C.S.B. Educational Multimedia Visualization Center site: *http://emvc.geol.ucsb.edu/downloads.php*.

Scroll down this page and choose the map titled **N.E. Pacific and W. North America Plate History, 38 Ma to Present**. Click on the map, then scroll right on the next page, and then click on download

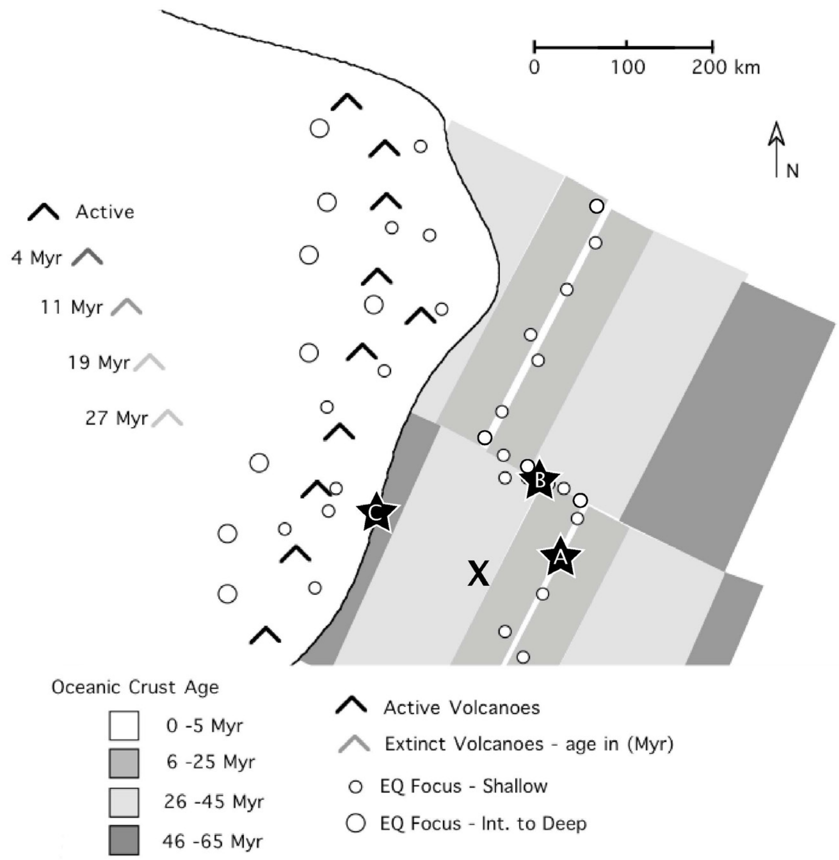
Play the animation video several times and observe the motion of the four plates interacting in the region represented in the video. Focus on the formation and evolution of the Juan de Fuca Plate.

In the space below write a brief summary of the history of plate tectonic interactions between the Juan de Fuca Plate and the North American Plate. Use the knowledge of plate tectonic activity gained in the Discovering Plate Boundaries activity and the Scientists' Ideas reading to describe the tectonic processes that are occurring at each plate boundary. Start your summary at 38 million years before the present and finish with what you think will happen after the Iuan de Fuca plate is completely subducted.

SUMMARIZING QUESTIONS

1. Look again at the 3D map of the world. Now imagine that you are a very patient person who never dies. Where on land or on the seafloor could you go to *observe* plates changing position?

2. Label the type of plate boundary that occurs at points “A”, “B”, and “C” on the tectonic map below. [NOTE: be sure to review the explanatory keys and sumbols on the map.]



3. Find the location X on the tectonic map. What type of plate (crust) is X a part of (continental or oceanic)? Explain your thinking. What evidence are you basing your reasoning on and what inferences are you making

What is the direction of motion of X relative to north? Explain your thinking. What evidence are you basing your reasoning on and what inferences are you making?

What is the direction of motion of X relative to a point “C”? Explain your thinking. What evidence are you basing your reasoning on and what inferences are you making?

4. Estimate as best you can, how far X would move in your lifetime? Explain your thinking. What evidence are you basing your reasoning on and what inferences are you making?

S. Sketch below a cross-sectional view of the plate boundary at “A”. Be sure to include (SHOW) all the evidence that your sketch is based on (i.e. earthquakes, volcanoes, geochronology, and geography).

6. Sketch below a cross-sectional view of the plate boundary at “B”. Be sure to include (SHOW) all the evidence that your sketch is based on (i.e. earthquakes, volcanoes, geochronology, and geography).

7. Mercedes, Fatima, & Bob, students in a geology class, wrote the following answers to the question: "What evidence for the motion of the plates would a 'patient' (i.e. never dying) astronaut see from space?"

   Mercedes: She would see a lot. The Atlantic Ocean would get bigger because of the divergent boundary in the middle. Mountains would grow and volcanoes would erupt on the top plate at convergent boundaries.

   Fatima: I think the best evidence the astronaut would see is plates sliding past each other like the San Andres fault.

   Bob: The astronaut would see earthquakes and volcanoes. Earthquakes and volcanoes happen at plate boundaries because of the friction.

   With whom to do you agree? Justify your answer using evidence from activities we have done.

8. Pick one of the students answers (above) that you do not agree with. What questions would you ask that student to help them develop a better understanding?

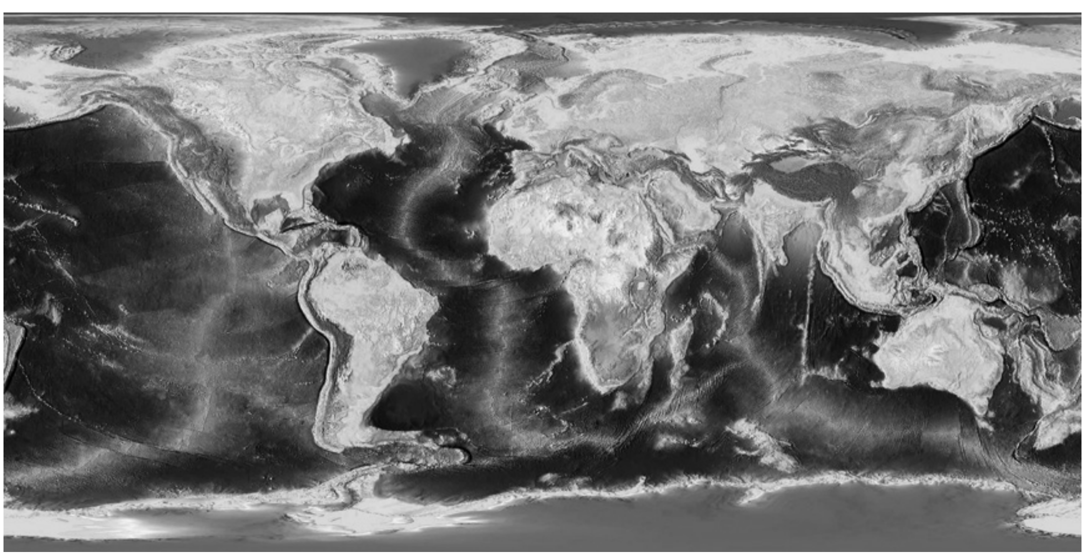
9. **Final Reflection**
   Part 1: Look back at your initial ideas about plate boundaries and plate motions. How has your thinking changed?

   Part 2: How do you see your efforts in this cycle as relating to the way that scientists do their work?

These questions are the prompts for your cycle reflection paper. You may type your answers on a separate sheet.

CYCLE 5

How does energy from inside Earth affect Earth's surface?



CYCLE 5

How does energy from inside Earth affect Earth's surface?

ACTIVITY 1 *The Energy from Within*

PURPOSE

Movement (direction and speed) of objects experiencing friction occurs only when an energy transfer occurs. The relationship between changes in motion and energy transfers is extensively explored in physics studies. If you participated in such a course, you should recall several ways that changes in motion relate to energy transfers. We have seen that tectonic plates move. These plates move very slowly compared to motions you are familiar with, yet the motion of the plates is constrained in the same way as the motion of any object experiencing a net force. Because the plates are massive and because there are huge "friction-like" forces on them, their continued motion requires a transfer of energy (and no small amount of energy either!). Where does this energy come from? The purpose of this activity is to explore the energy transfer mechanisms that drive the motion of tectonic plates.

Q. How does energy transfer occur inside the Earth?

INITIAL IDEAS

On your own answer the following:

What ideas do you have about energy inside the Earth? Describe or sketch how this energy could be transferred and transformed into plate motion energy (kinetic energy)

Share your ideas with your group then brainstorm and record a way that energy from the Earth's *interior* could a) reach the surface, and b) maintain plate movement?

Class Discussion

Whiteboard your groups ideas and share them with the large group. Write down any ideas that are different from your own.

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *Heat Energy Interactions*

YOUR GROUP WILL NEED

- energy interaction diagram (11"x17") for each person

DEMONSTRATION MATERIALS (one set per classroom)

- hot plate
- frying pan
- egg
- lamp with 100 W bulb
- glitter lava lamp

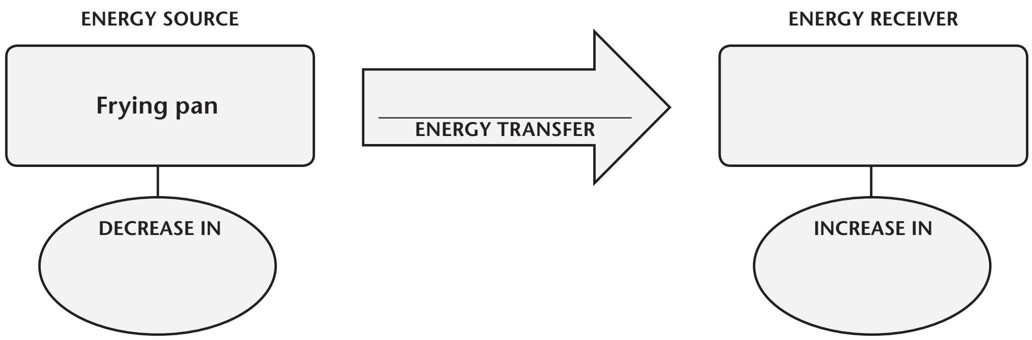
In Cycle 2, you diagrammed the transfer of heat energy. But what kind of heat energy transfer was it? If you look at your Energy Transfer Chart, you will see that heat energy transfer can occur through three interaction types: infrared interaction, conduction interaction, and convection interaction.

Observe the demonstration tables in the front of the room for examples of each of these three types of heat energy transfers.

Conduction interaction:	Fry an egg on a hot plate
Infared Radiation interaction:	Turn on a 100 W bulb and put your hand near the side of it (but not touching). Feel the heat!
Convection interaction:	Watch the lava lamp!

Fill in the following energy diagrams for each of those interactions.

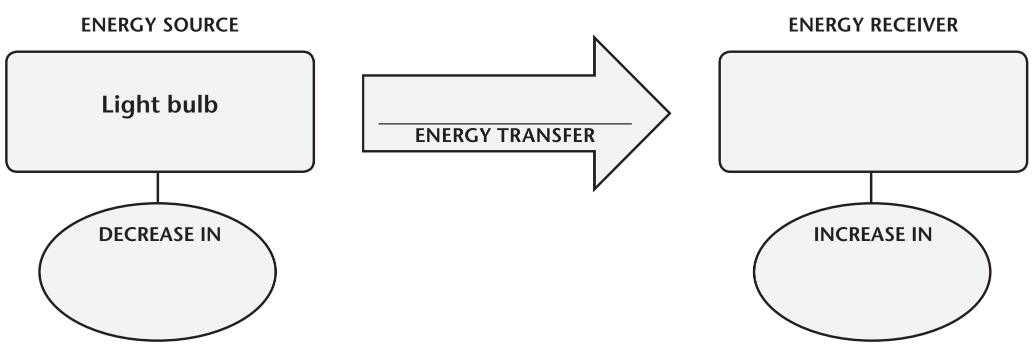
CONDUCTION INTERACTION



Explanation:

This diagram would require another one before it to describe the transfer of energy between the hot plate and the frying pan.

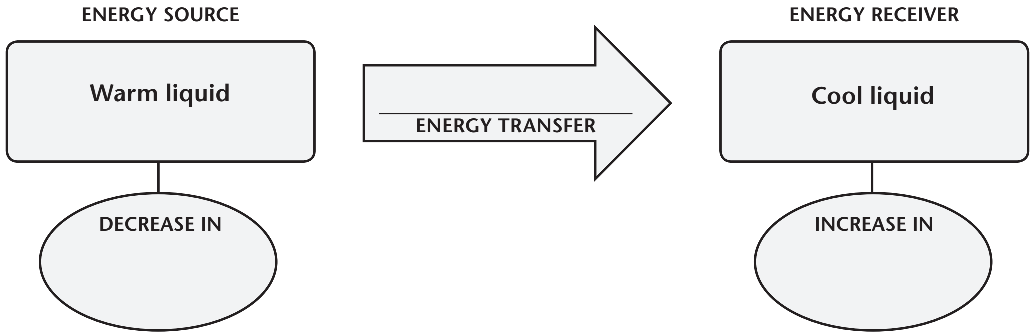
INFARED RADIATION INTERACTION



Explanation:

CONVECTION INTERACTION

Note: A convection interaction implies a gravitational interaction. When you display a heat convection interaction, you do not need to separately specify the mechanical energy transfer (although you should recognize that it occurs!).



Explanation:

This diagram would require another one before it to describe a conduction interaction between the light bulb and the liquid. It would need another one after it to describe the conduction interaction between the liquid and the glass on the sides and top.

How are these interaction types similar? How are they different?

Be prepared to whiteboard your answer to the above question, along with your three types of heat energy diagrams, and share with the rest of the class.

EXPERIMENT 2 *Heat and Expansion*

In Cycle 3, you worked with the concept of density. Now we will expand on that understanding to see how density is affected by temperature.

YOUR GROUP WILL NEED

- metal rod with attached ball
- metal rod with attached hoop
- one class bunsen burner
- Erlenmeyer flask and rubber stopper
- glass tube that fits into rubber stopper
- scale capable of measuring 1kg mass
- hot plate
- water
- safety goggles

Experiment 2A will take 3-4 minutes of waiting. You might want someone from your group to be setting up Experiment 2B in those minutes.

EXPERIMENT 2A

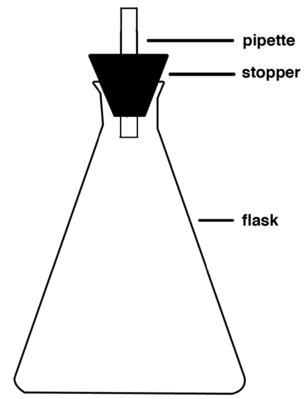
Obtain a metal rod with attached ball and note that it fits through the metal hoop. Holding the ball by the wooden handle, heat the ball over a flame for 3-4 minutes. Now try to fit the ball through the hoop. What happened to the ball? Why do you think that happened?

Did the volume of the ball change? Did the mass of the ball change? How do you know?

Did the density of the ball change? Why or why not?

EXPERIMENT 2B

Set up an Erlenmeyer flask on a hot plate. Fill flask to the top with water and cap with a rubber stopper with a 5 ml glass tube. Weigh the flask. Heat the flask over a hot plate. What do you observe happening in the glass tube? Why does this happen?



Did the volume of the water change? Did the mass of the water change? How do you know?

Did the density of the water change? Why or why not?

Discuss your results in your group.

EXPERIMENT 3 *How does temperature affect density?*

YOUR GROUP WILL NEED

- four clear plastic bottles (500 ml)
- red food coloring
- hot and cold water
- two 3x5" plastic coated, stiff cards (e.g. large playing cards)
- OPTIONAL: 1 liter of cooking oil per classroom

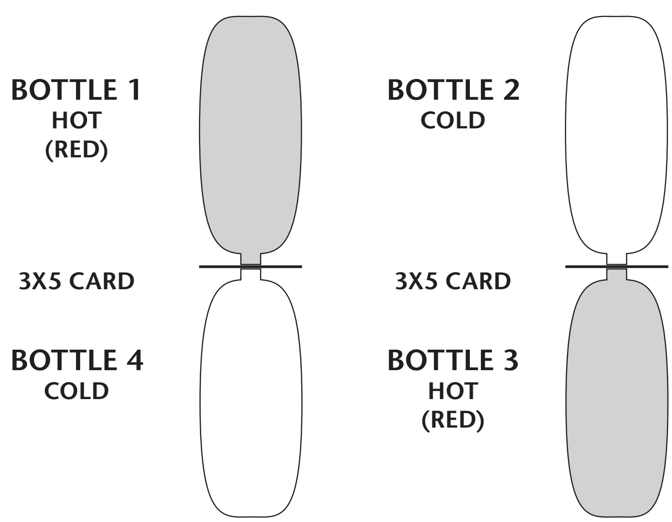
STEP 1

In your group, completely fill four plastic bottles as follows.

Bottle 1	**Hot water with red food coloring**
Bottle 2	**Ice-cold water**
Bottle 3	**Hot water with red food coloring**
Bottle 4	**Ice-cold water**

STEP 2

Cover Bottle 1 and Bottle 2 with 3x5" paper cards. Hold card tightly on top of Bottle 1 and turn bottle over (without spilling liquid) and place on top of Bottle 4. Turn Bottle 2 over (without spilling liquid) and place on top of Bottle 3. **Do not remove card.**



STEP 3

On your own, predict what will happen when you remove the cardboard squares that separate the liquid in the two plastic bottles. Explain your reasoning for this prediction.

STEP 4

Carefully remove the cardboard squares that separate the liquid in the two plastic bottles (do both sets at the same time.) Describe what happens in both sets of bottles.

Why do you think this happened?

SUMMARIZING QUESTIONS

1. Based on the last three experiments, what can you say about the relationship between density and temperature? Think about how to answer this without using the word "molecule" or "atom."

2. In the last three experiments, was a difference in mass or a difference in volume responsible for the density difference? How do you know?

Class Discussion

In your group, whiteboard your results of the experiment and your thoughts on the above two questions. Be prepared to share your answers with the class.

Was there a heat energy transfer between Bottles 2 and 3? How do you know?

What type of heat energy transfer was it? (conduction? convection? infrared radiation?) Why did you choose the one you did?

Was any heat energy transferred between Bottles 1 and 4? How do you know?

If you think there was a heat energy transfer, was it a heat conduction interaction, a heat convection interaction, or an infrared radiation interaction? How do you know?

Class Discussion

In your group, for each pair of bottles, whiteboard your thoughts on the type of heat transfers that occured. You can use energy diagrams, but be sure to explain your thinking.

DEMONSTRATION

Your instructor will replace the cold water in the bottles with cold cooking oil. How do you think the results of the experiment will change? Write down your thoughts below.

EXTENSION QUESTION

Draw a "particle" view of the warm and cold:

a. water in bottles
b. metal ball
c. gas

EXPERIMENT 4 *Lava Lamp Analogy — How does internal heat flow through the Earth?*

YOUR GROUP WILL NEED

Lava lamps (NOTE: pre-warm lava lamps overnight or this will not work)

- outlet (extension cords might be needed)

Who isn't mesmerized by the moving blobs of wax or glitter in a lava lamp? Why do you think the wax moves in the way that you observe? Observe and compare blobs of different sizes (their speed, shape, direction of motion).

On Your Own: Answer the following questions.

What do you notice about the motion of the wax? Record as many observations as you can.

What is the source of energy for wax blob motion? Why do you think that? What is your evidence?

What happens to the wax over a period of a few minutes once it is in motion?

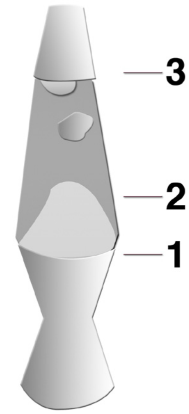
Does the motion occur if the light is on or off? Why or why not?

What evidence supports the idea that the wax is involved in some sort of energy transfer or interaction once it is rising?

Write an explanation for this interaction using your energy transfer and interaction chart.

Why do you think the wax eventually drops back toward the bottom? Use what you learned about density and heat expansion to explain your reasoning.

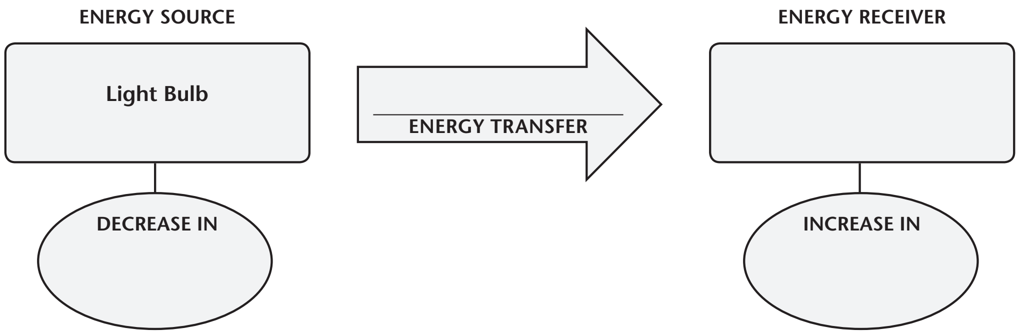
Share your thinking with your group. Did your group members have any different explanations for the motion of the wax?



Class Discussion

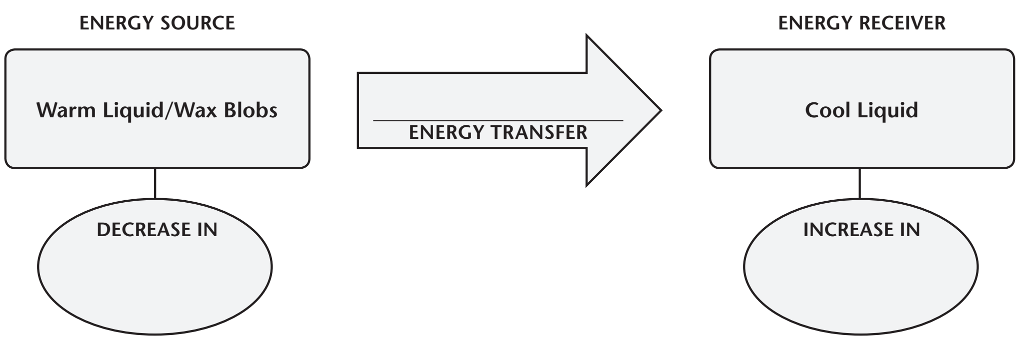
On a whiteboard, develop at least three energy diagrams for the liquid/wax blobs 1) lying at the bottom near the light bulb, 2) rising up in the middle, and 3) resting at the top near the cap, as shown in the drawing. Be prepared to share with the entire class

1.



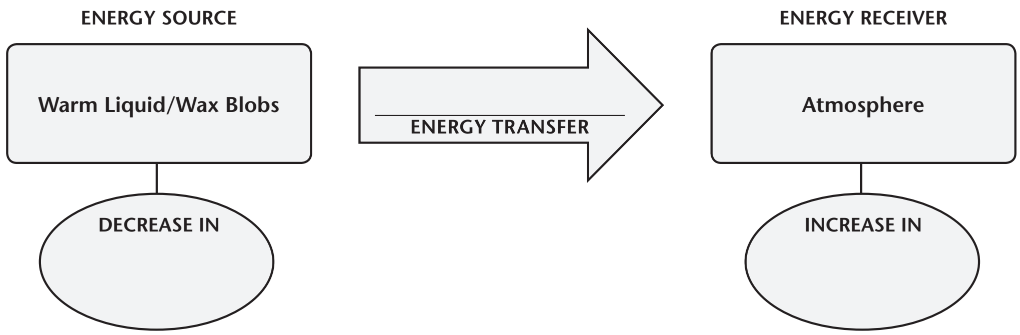
Explanation:

2.



Explanation:

3.



Explanation:

Write down any new ideas presented by your classmates that help you understand the energy transfers in the lava lamp.

EXPERIMENT 5 *What drives plate tectonics?*

Earth's mantle is nearly 3,000 km thick and occurs between the crust and the molten outer core. Although mantle rocks behave like a brittle solid on short timescales associated with earthquakes, they seem to flow like a very thick fluid on longer time scales of days to years. Geologists use a technique called *seismic tomography* to detect this mantle flow.

The word tomography (Greek: *tomos* = slice, *graphein* = to write) refers to the process of making drawings of slices through an object or person. Geologists use seismic tomography to view slices of Earth's interior similar to the way that medical technologists view slices of the human body. The human body slices are known as CAT (computer axial tomography) scans and are constructed using X rays to penetrate and image the human body. The tomography scans of Earth's interior are constructed using seismic waves to penetrate and image the body of Earth.

In seismic tomography, geologists collect data on the velocity (rate and direction) of many thousands of seismic waves as they pass through Earth. The waves travel fastest through rocks that are the most dense and presumed to be coolest. The waves travel slower through rocks that are less dense and presumed to be warmer. When a computer is used to analyze all of the data, from all directions, it is possible to generate seismic tomography images of Earth. These images can be viewed individually or combined to form three-dimensional perspectives. The computer can also assist in false-coloring seismic tomography images to show bodies of mantle rock that are significantly warmer (red) and cooler (blue) than the rest of the mantle.

FIGURE 5-1
Seismic tomography image (horizontal slice) of Earth's mantle at a depth of 350 km. Red (false-coloring) indicates hot rock that is less dense and ascending in comparison to the blue-colored cooler rock that is static or descending (courtesy of Paul J. Morin, University of Minnesota). For areas of no color (black), there is no information.

Paul J. Morin, tomography slice of Earth, from Laboratory Manual In Physical Geology 7th Ed. *by Richard M. Busch & Dennis Tasa.*

Please go to *http://www.classzone.com/books/earth_science/terc/content/investigations/es0402/es-0402page09.cfm?chapter_no=investigation* to examine these regions on a rotating globe.
Then click on Step 10 to examine descending mantle beneath South America in 3D.

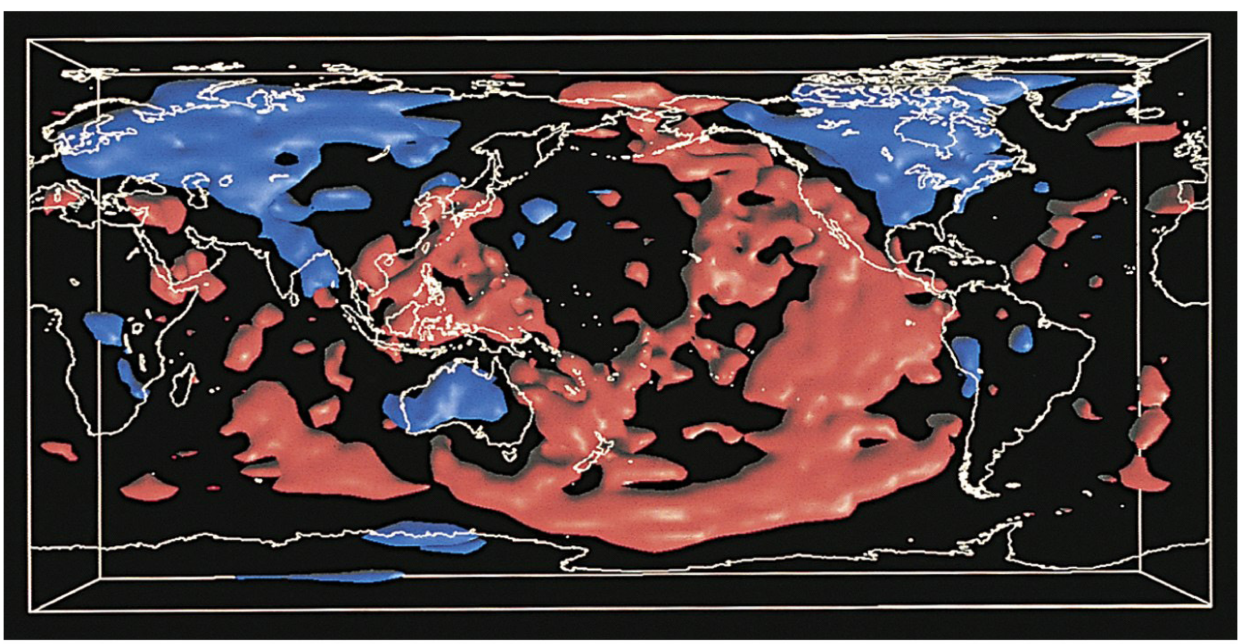


Figure 17-14 The Sciences: An Integrated Approach, 5/e

QUESTIONS

Observe Figure 5-1 and play with the online globe model. Unlike the lava lamp that you viewed from the side, this is a layer of Earth's mantle at one depth and viewed from above

How is the motion of Earth's mantle like a lava lamp and how is it different?

Compare the plate boundary maps (Earth's surface) from Cycle 4 (locations and types) with the 350 kilometer depth layer in Figure 5-1.

What features occur below the locations of **divergent** boundaries (e.g., Mid-Atlantic)? How good is the correlation between the features in the mantle and divergent plate boundaries?

What features in Figure 5-1 occur below the locations of **convergent** boundaries (e.g., west coast of South America)? How good is the correlation between the features in the mantle and convergent plate boundaries?

Transform boundaries are not evident from this data. Why not? (explain your reasoning)

Draw a vertical cross section of Earth that shows how you think mantle convection could relate to plate tectonics (plate boundary locations, plate movement and boundary types). Make sure to include continental and oceanic lithosphere, a ridge system, a subduction zone, and color coded regions of hotter or cooler mantle material. Add arrows to indicate the motion of mantle material and plate movement.

Reflective writing: *Review your initial ideas on what causes the plates to move and how energy gets transferred inside Earth. What have you learned while observing the lava lamps and tomography data?*

EXPERIMENT 6 *A model of heat flow in Earth*

Select "Animation 4" on the Caltech Geodynamics Website.
http://www.gps.caltech.edu/~gurnis/Movies/Dynamic_Int_EI/movie4f.mov

This is one of many models of heat flow in Earth's mantle. It represents the flow of heat from the core to the surface. Particularly notice how the cooler region in blue drops through the mantle, while the less dense material at the core floats up just like wax in a lava lamp.

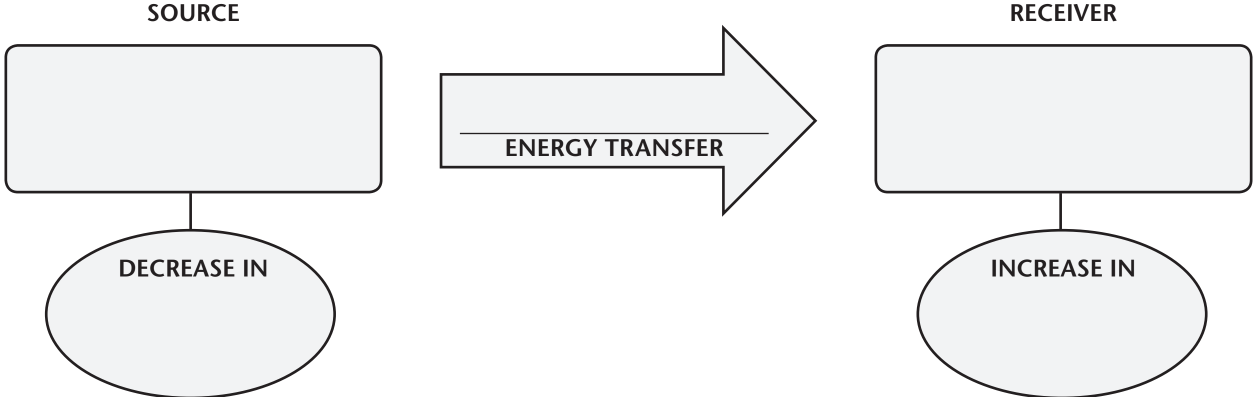
OPTIONAL QUESTION: Why might the blue material pool on the black line before it drops through? (hint: imagine a scenario where sinking material might get "held up" as it sinks)

The previous exercises offer insight on how convection works in Earth. Plate boundaries are locations where vertical motions of the interior interact with plates e.g., cold dense material sinks at subduction zones and warm less dense material rises at spreading centers. But what happens to the plate's interior as it moves? Review what you have learned about the way a plate moves (Cycle 4, Activity 2). Draw a diagram on your whiteboard showing how mantle motion may be related to horizontal plate motions. Be prepared to share these ideas in a class discussion.

SUMMARIZING QUESTIONS

Review the energy diagrams for heat flow you developed in this activity. Complete the energy diagram below for an interaction in which the lamp causes the wax to move upward:

_______________________________Interaction



Explanation:

Describe a process by which energy from deep within Earth could flow to the surface, similar to energy flow in a lava lamp.

Before going on to more questions, read the following Scientists Ideas.

SCIENTIST'S IDEAS
Earth's internal energy and Plate Motion

Mantle Convection
The Earth's surface and its interior are both in motion. Below the lithospheric plates (which are rigid), the mantle is very hot and can flow, albeit slowly, in response to steady forces applied for long periods of time. Just as solid metal, when heated and pushed, can be softened and take different shapes, solid rock in Earth's mantle can deform in response to millions of years of heat and pressure.

The mobile rock beneath the rigid plates is believed to be moving in a circular manner somewhat like a pot of thick soup when heated to almost boiling. The heated soup rises to the surface, spreads, cools, and then sinks back to the bottom of the pot to be reheated again. This continuous cycle generates a circular current called a convection cell or convective flow. While convective flow can be observed easily in a pot of soup, the idea of such a process stirring up the Earth's interior is much more difficult to grasp. While we know that convective motion in the Earth is much, much slower than that of heating soup, many unanswered questions remain: How many convection cells exist, and are there layers of currents or one big current (see images below)? Where and how do they originate? And what is their structure?

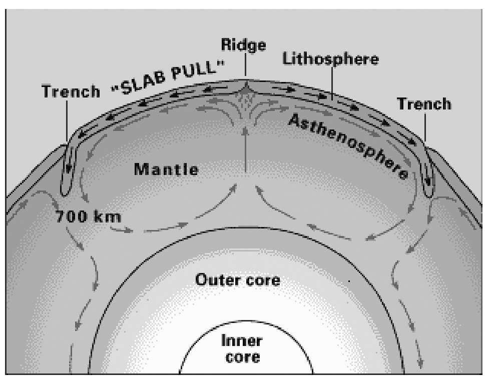


Figure 5-2. Conceptual drawing of assumed convection cells in the mantle. Below a depth of about 700 km, the descending slab begins to soften and flow, losing its form.

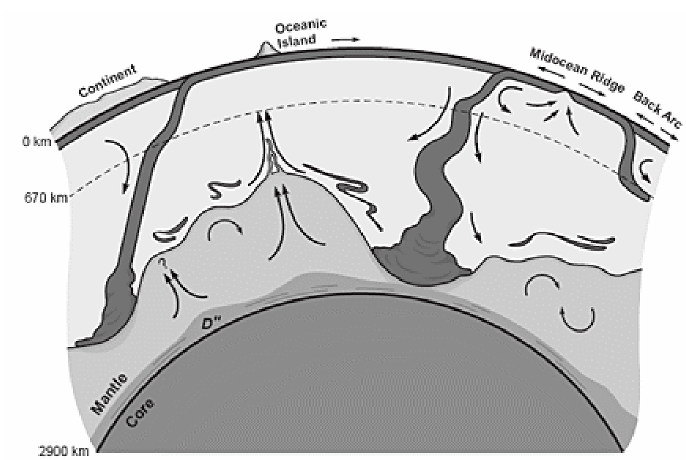


Figure 5-3. Diagram illustrating the possible dynamics of the mantle. In this interpretation there are distinct layers containing local convection cells. As with the other diagram, internal circulation is driven by internal heating and by heat flow (Kellogg et al., 1999).

Internal Sources of Energy

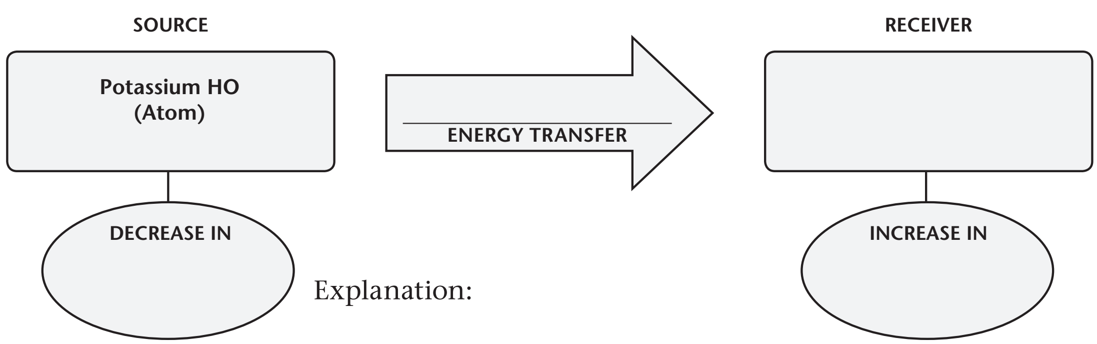
Convection cannot take place without a source of energy. Earth's internal energy comes from two main sources: ***radioactive decay*** and ***residual heat***.

A. ***Radioactive decay*** of naturally occurring chemical elements deep inside the Earth—like uranium, thorium, and potassium—releases thermal energy, which slowly migrates toward the Earth's surface. Radioactive decay is the loss of particles (and energy) from the nucleus of an element. This process releases a lot of energy. A nuclear power plant gets its energy from a chain-reaction radioactive decay in which the decay happens at a very fast rate.

This introduces a new type of energy interaction, the **nuclear interaction** (see Table 2-4). For those interested, the more complicated definition is that energy is stored in the fields of the nuclear force through the geometry of the protons and neutrons much like chemical energy is stored in the electrical fields of the electrons. The energy is transferred through the emission of particles (with mass or photons) that transform their energy through mechanical or light interactions with surrounding atoms into thermal energy. For our purposes we can simply state that the **nuclear energy interaction** occurs when a source atom (isotope) decays decreasing in stored nuclear energy. There is a heat energy transfer that causes the surrounding environment to increase in thermal energy.

Complete an energy diagram for an interaction in which a potassium-40 atom decays and releases energy to surrounding mantle material:

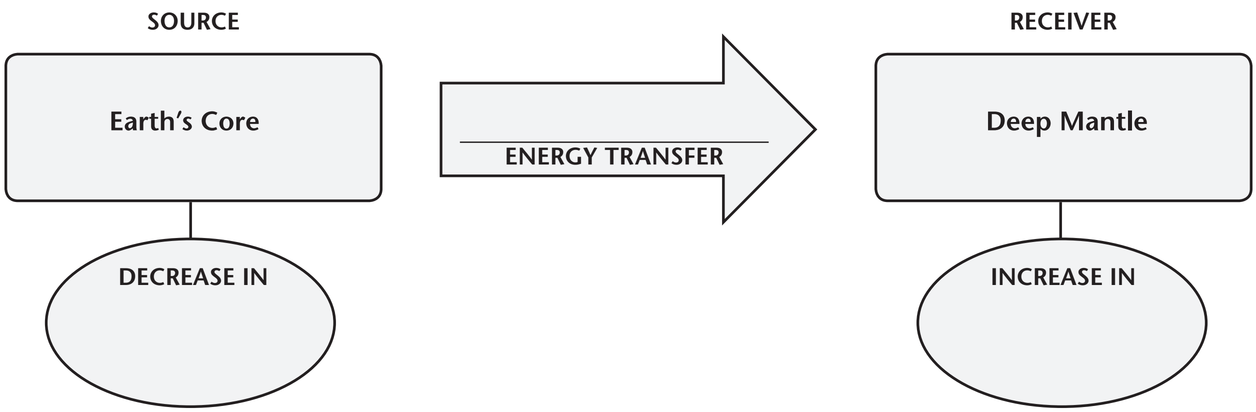
Interaction Type ______________



B. ***Residual heat*** is thermal energy left over from the formation of the Earth 4.6 billion years ago. The "falling together" and compression of cosmic debris to form this and other planets heated the debris to tremendous temperatures (motion energy transfers to thermal energy on impact). The gradual migration of this residual heat (along with radioactive decay generated heat) towards the cooler surface helps establish convection in the mantle. How the upwelling/downwelling parts of the convection cell initiate in a particular region remains a mystery.

1. Complete energy diagram 1 below for an interaction in which energy generated from deep within the Earth causes deep mantle material to heat up:

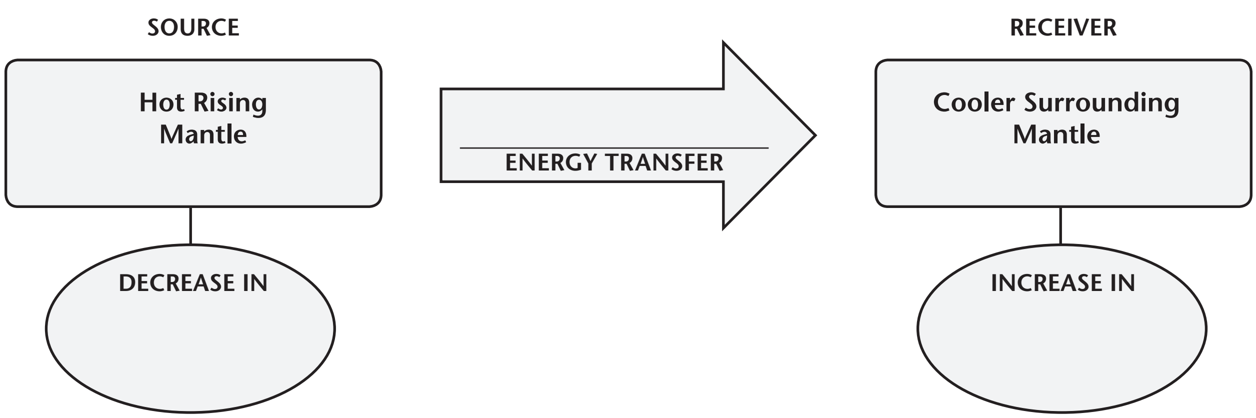
Conduction Interaction



Explanation:

2. Complete energy diagram 2 below for an interaction in which energy is transferred from deep hot mantle material moving upwards towards Earth's surface.

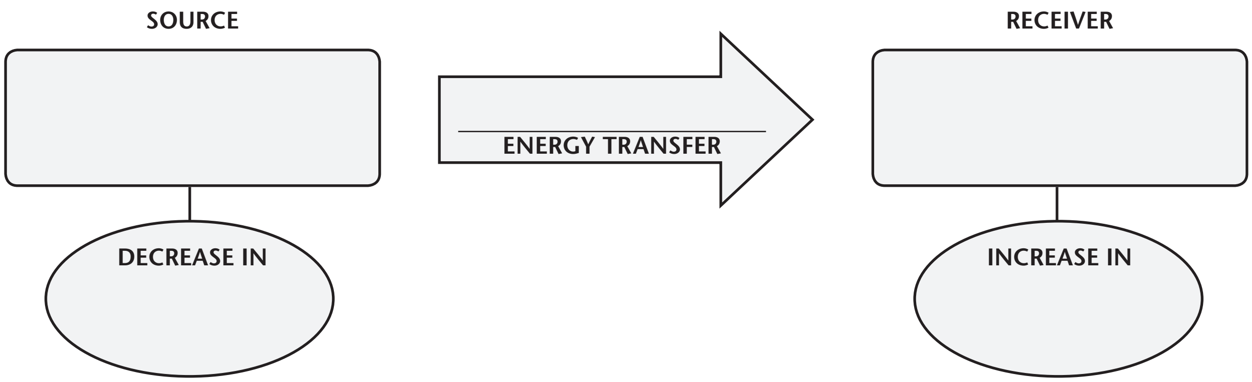
_____________________ Interaction



Explanation:

3. Complete energy diagram 3 below for an interaction in which energy transferred from hot mantle material near Earth's plates causes the plates to warm.

______________________________ Interaction

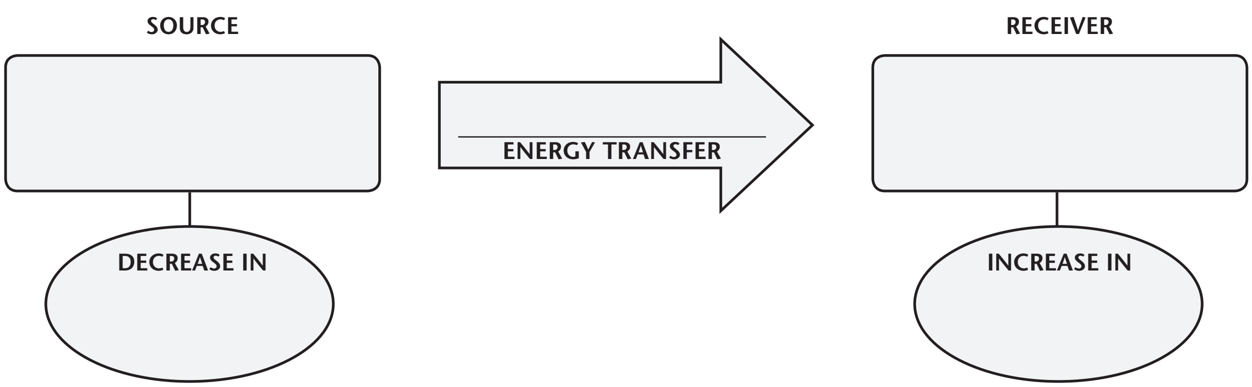


Explanation:

4. If the plate is warm at a divergent boundary, why does it eventually descend at a convergent boundary (subduction zone)? (Hint - think of the lava lamp)

5. Complete an energy diagram for an interaction in which energy is transferred from the plates heated in 3 to the atmosphere. You can continue many more of these interactions outward. Where does all the heat from Earth's interior ultimately end up?

___________________________Interaction



Explanation:

☑ **CHECK IN WITH YOUR INSTRUCTOR**

On the drawing, show the locations where diagrams 1, 2, and 3 and 5 are most likely to occur within Earth. Then compare your drawing with the lava lamp figure in Exercise 1 of this activity. On a whiteboard, sketch your drawing and describe how you think material flowing in the mantle may cause different types of plate tectonic features (for example, subduction zones, divergent boundaries, and horizontal motion of the plates).

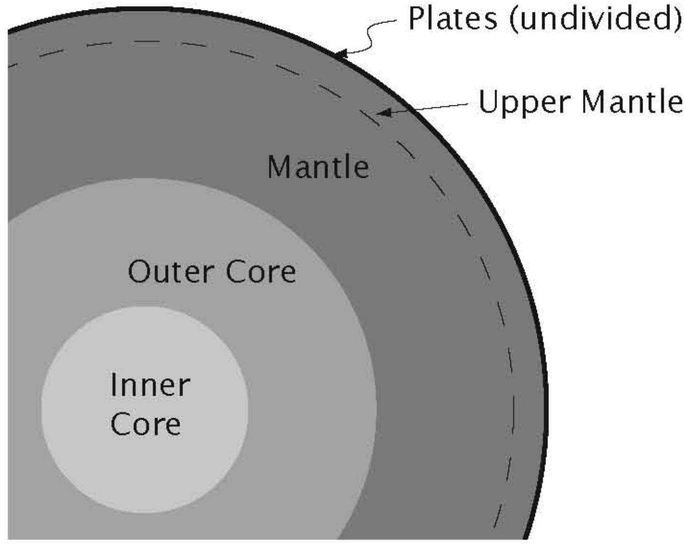


FIGURE 5-4

Note, this diagram is not to scale. The plate layer is too thick.

REFLECTIVE WRITING

Presumably your ideas about how heat flows in the Earth have changed. Can you identify specific places in the curriculum that had the greatest impact on your thinking? Explain how your thinking changed in each instance?

ACTIVITY 1: HOMEWORK

Name ______________________________ *Date*________________

Heat Transfer, Expansion/Contraction, and Density

1. Heat is transferred by: A. Conduction B. Infared Radiation C. Convection

   For each of the interactions listed below, write down the letter (A, B, C) (or letters) for the type of heat transfer involved:

   You open up your car on a sunny day and the interior is much hotter than the outside air.

   ______ The air temperature directly above a pool of lava is much hotter than the surrounding air.
   ______ You go swimming in the ocean, but your skin becomes too cold and you have to get out.
   ______ There are hot spots beneath oceanic plates, where hot mantle material is rising.
   ______ After the sun sets, you hold your hand close to a road surface, and you feel warmth.
   ______ You cannot hold an ice cube in your hand for long, before your hand gets too cold.
   ______ You put an empty pot on a hot stove and then discover that the pot handle is too hot to touch.
   ______ Even though a pot filled with water is only heated at the bottom, water on top is also hot.
   ______ As an oceanic plate is subducted into the mantle, it heats up.
   ______ The heating vent is on the opposite side of the room from you, yet you still feel warm.

2. Use the results from Activity 1 experiments to explain how a hot air balloon rises into the atmosphere:

3. Geologists argue over what is actually causing Earth's plates to move. One idea is that the mantle is in motion, and that the plates are being pulled along by that flow. Another idea is that dense ocean floor descends into the mantle at trenches, pulling the rest of the plate along with it. In either case, the motion is a result of density differences that occur when something is heated or cooled. Remember that when a substance is heated, it tends to expand and therefore become less dense; likewise, when a substance is cooled, it tends to contract and therefore become more dense.

   a. Explain how heating and/or cooling could cause motion within Earth's mantle:

   b. Explain how heating and/or cooling could cause ocean floor to descend into trenches.

ACTIVITY 2 *The Energy of Earthquakes*

PURPOSE

In Cycle 4 we saw that the Earth's surface is divided up into plates that move relative to one another. In Cycle 5, Activity 1, we saw that the interior of the Earth is moving due to the sinking of cold, dense mantle rock, and the rising of warm, less dense, mantle rock. These movements in the mantle are linked to the movement of the plates, and imply energy transfers are taking place.

Earthquakes are one way in which we can directly observe plate movement. Many of us have felt the unsettling motion of even a small earthquake. The motion results from the energy transfer processes that occur during sudden and rapid plate movement.

In this activity we will investigate the transfer of energy that takes place at the edges of plates (and often in their interiors) as they move during an earthquake. This transfer of energy is in the form of earthquake waves (motion energy).

As earthquake waves travel through Earth, they also provide us with a way to remotely study what the inside of Earth looks like. Much like a doctor uses x-rays to map the inside of our bodies (CAT scans), geophysicists use earthquake waves to map Earth's interior.

Q. Where does the energy for earthquakes come from and how does an earthquake transfer energy? How can we use earthquake energy to figure out what is inside Earth?

INITIAL IDEAS

In October of 1989 a large earthquake occurred in Loma Prieta, 70 miles south of San Francisco. The Loma Prieta earthquake (so called because of the location of the epicenter) devastated many areas flattening buildings and highways.

On your own, answer the following:

How did the energy from the Loma Prieta earthquake knock down structures 70 miles away in San Francisco?

Where does the energy for an earthquake (anywhere on Earth) come from? How do you know?

Formulate some ideas on how this energy can move through Earth.

Class Discussion

Share your ideas with your group, and then participate in a class white-board discussion about your group's ideas.

EXERCISE 1 *Where does earthquake energy come from?*

YOU WILL NEED

- Stick-Slip demo setup
- Energy interaction charts

Draw the stick-slip demo setup and describe it below.

What do you predict will happen when your instructor turns the crank?

Did you predict that the block would move immediately? If so, why? If not, why not?

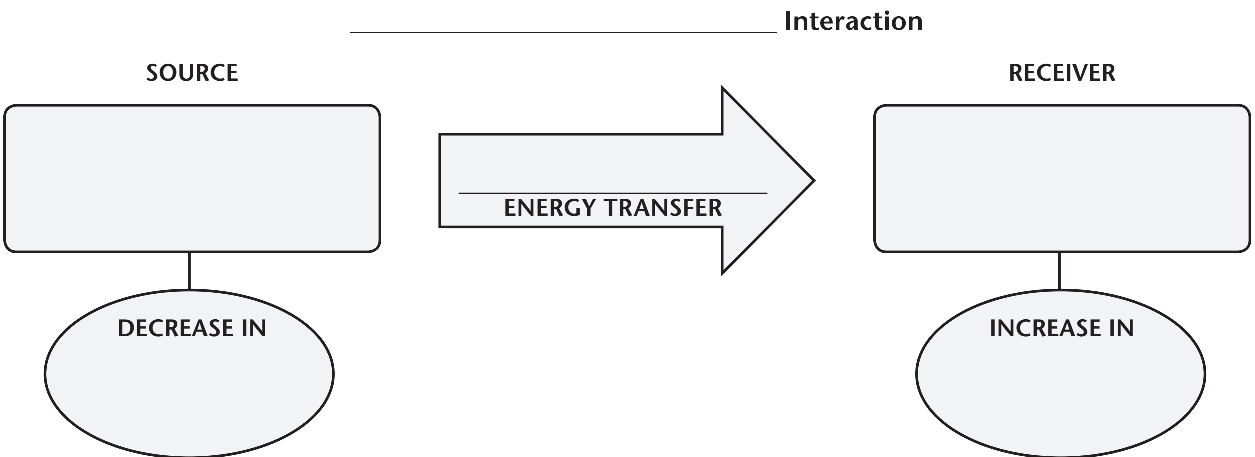
What type of energy interaction is occurring during block slip? What forms of energy are involved? Be sure to use your energy interaction chart to help you with this.

What type of energy interaction is occurring when the block does not slip but the scale reading increases? What forms of energy are involved?

Can you think of other examples where energy may be stored by stretching or changing shape before that energy is quickly released? (PET students: think back on your experiments with cars and rubber bands). Can you think of a way Earth could store energy and then quickly release it?

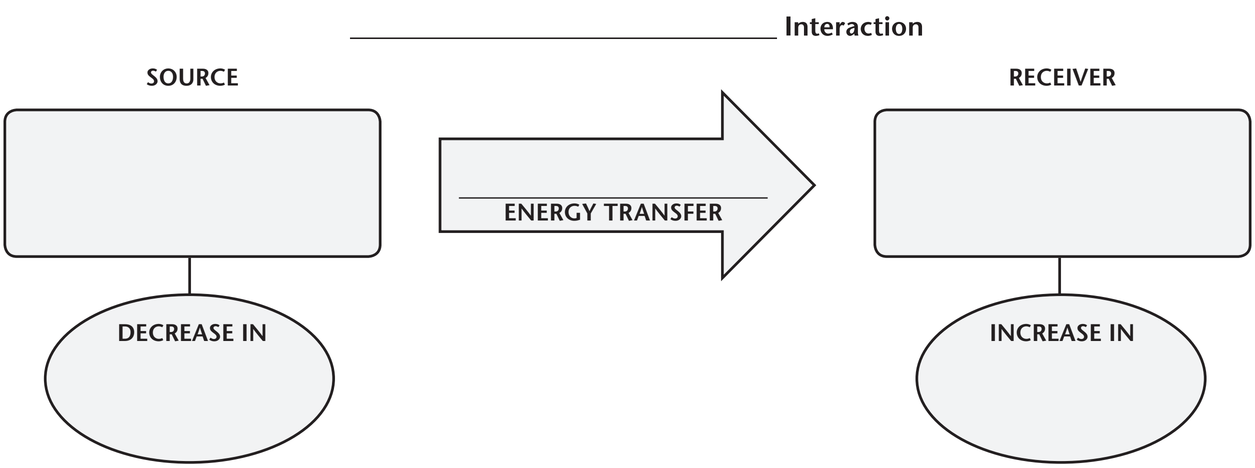
In your small groups come up with some ideas of where the energy from the crank is going between slips (i.e., when crank is moving, but the brick is not). Secondly, relate your observations to Earth and Earth processes. In what way(s) is this analogy similar to what happens during an earthquake? In what way is it different? Include in your discussion how this analogy might relate to plate motion you learned about in the last cycle. Whiteboard your ideas.

Use the analogies we have seen to complete the following energy diagram for an interaction in which rock material ***builds up*** energy from the mantle material underneath it:



Explanation:

Complete the following energy diagram for an interaction in which rock material ***releases*** built up energy causing the earth (nearby rock) to move:



Explanation:

Revisit your initial ideas about the Loma Prieta earthquake. If the energy of the earthquake was released in a fashion analogous to the diagrams above, how did this energy travel 70 miles to reach San Francisco? Discuss with your group.

How do these Energy diagrams relate to Energy diagrams you drew in PET? How are they different?

Class Discussion

Draw your energy diagrams on a whiteboard and be prepared to discuss them with the class.

EXERCISE 2 *How is earthquake energy transferred through different materials?*

YOU WILL NEED

- your classmates
- stopwatch
- calculator

MODEL EXPLANATION: READ BEFORE GETTING STARTED:

The activity described below is a model of how earthquake waves travel through Earth. Scientists use models to help understand complex systems within Earth. In this model, students represent molecules that make up rocks/magma inside Earth.

Students with "linked" arms represent solid rock (molecules tightly linked).

Students with unlinked arms represent molten rock (molecules not linked).

Earthquakes are represented by "pushes" that travel through a line of students. Our variables will be the phases of matter (liquid vs. solid), the density of the matter (solid), and the type of earthquake wave (a parallel push versus a perpendicular push).

Students will line up in a long row and follow the directions in the "Student action" column. One person will be a "pusher" and will follow directions in the "Pusher action" column. The last student in the line will yell 'got it' and raise her/his hand when s/he feels a push from her/his neighbor.

Read the descriptions below and respond to the predictions below:

RUN #	STUDENT ACTIONS	"PUSHER" ACTIONS
RUN 1	**All students should link arms** and hold their	Push the first student in line **parallel** to the line. arms **firmly** together.
RUN 2	SAME AS ABOVE	Push the first student in line **perpendicular** to the line.
RUN 3	**All students should link arms,** move slightly further apart, and hold their arms **loosely** together.	Push the first student in line **parallel** to the line.
RUN 4	Students in the **first half of the line should link arms** and hold their arms **firmly** together, as in run 1, and students in the **second half should not link** their arms but stand at the same spacing as linked students.	Push the first student in line **parallel** to the line.
RUN 5	SAME AS ABOVE	Push the first student in line **perpendicular** to the line.

PREDICTIONS

Do you think Run 1, parallel push with tightly linked arms and closely spaced, and Run 3 with loosely linked arms and wider spacing, will be different in any way? If so, why? If not, why not?

Refer back to Cycle 3, Activity 1. How would you estimate the density of this line of people? Which represents a "more dense" line, Run 1 or Run 3? Which will be faster?

Do you think Run 1 (parallel push with tightly linked arms) or Run 2 (perpendicular with tightly linked arms) will be faster? Why?

Discuss your predictions with your group.

PROCEDURE

1. The class should select a timekeeper and data recorder. The process will consist of the instructor sending seismic waves (in the form of a push) through Earth (as modeled by you and your classmates). What will differ is the nature of the push, and the type of Earth material that you are representing.

2. Find a space where you and your classmates can line up shoulder to shoulder in a single straight line.

3. For each trial of each run the instructor will gently push the first person in line while simultaneously calling out, "go!" When the last person in line feels the push, she/he will yell "got it" and raise her/his hand for the timekeeper.

4. Students should fill in the travel times for each of the runs on the table below:

DATA TABLE

RUN	TRIAL 1 TIME	TRIAL 2 TIME	TRIAL 3 TIME	AVERAGE TIME
1				
2				
3				
4				
5				

RESULTS

Discuss these questions with your group, and construct your answers together.

1. Did your predictions match the actual results of the experiments? Explain.

2. What differences in the properties of Earth materials are being modeled by changing the way that students are arranged in Runs 1 and 3?

3. How might the differences in wave speed in Runs 1 and 3 relate to the differences between the red and blue areas in the seismic tomography figure (Figure 5-1)?

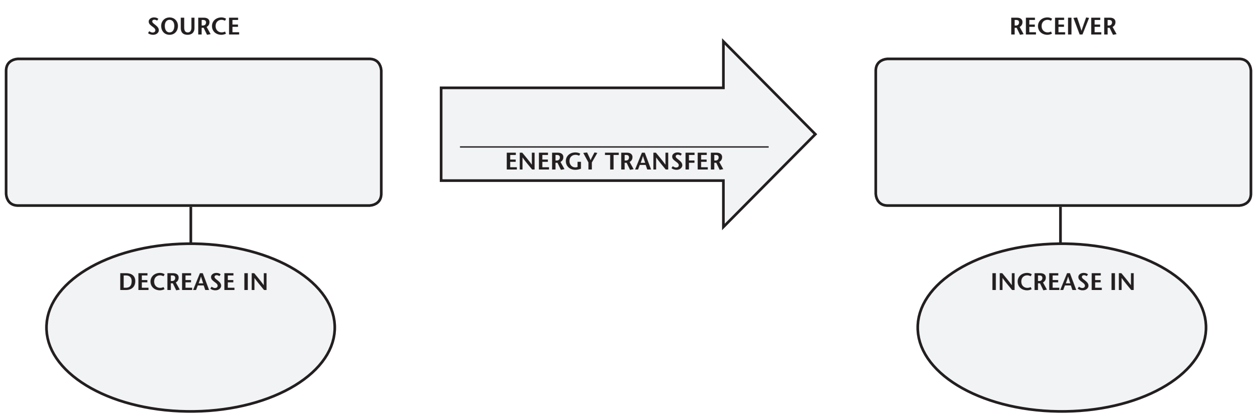
4. What differences in the properties of Earth materials are being modeled by changing the way students link their arms in runs 4 and 5 compared to Runs 1, 2 and 3? (Hint - Read "model explanation")

5. If you compare Runs 4 and 5, why did they produce such different results? What is different about the way that a parallel push moves through **unlinked** people and the way that a perpendicular push moves through **unlinked** people?

6. Consider the results of all five runs. In what way are the perpendicular and parallel pushes a similar process? In what way are they different? Which moves faster through the human line?

7. What kind of energy transfer (interaction type) is involved as the push makes its way down the line of people with tightly linked arms? Use the following energy diagram to describe this transfer of energy.

______________________ **Interaction**



9. How do you think the phases of matter (solid vs. liquid) influence the ability to transfer the energy that you diagrammed in question 7?

9. What are the strengths and weaknesses of these particular analogies of human chains representing material in Earth's interior?

Discuss your answers to questions 2-8 with your group, and participate in a class discussion of your group's ideas on how density and phases of matter affect the transfer of mechanical energy.

DVD clip. How do waves move?

- What concepts do you see these 2nd grade students demonstrating? Based on the K-2 Benchmarks, do you think this is an appropriate demonstration for this age?
- Based on your exploration of the Atlas, which age group do you feel would most benefit from this demonstration?
- What building blocks of understanding would be appropriate for these 2nd grade students to help them later develop their understanding of the structure of matter?

EXERCISE 3 *How do waves transfer energy?*

YOU WILL NEED

- a Slinky (two if you have them)
- a 5-Slinky block
- a partner

The Slinky is yet another use of a analogy to illustrate an Earth process.

Stretch the Slinky between your partner and yourself so that the rings are about 2 cm apart. Or, tie one end of the Slinky to a chair or other solid object.

1. Pull the Slinky toward you a bit and then push it away. Observe the motion of the Slinky metal rings versus the motion of the wave you generated. What do you notice about the wave motion?

Which human wave run in the previous exercise did this resemble? Explain your reasoning.

Draw the Slinky in motion with arrows representing the direction of the rings (your hand motion) and the waves.

2. Give one sharp pulse on one end of the Slinky from side to side. Observe the motion of the Slinky metal rings versus the motion of the wave you generated. What do you notice about the waves motion now?

Which human wave run did this resemble? Explain your reasoning.

Draw the Slinky in motion with arrows representing the direction of motion of the rings (your hand motion) and the waves.

Seismic Wave Definitions

Adapted from http://science.howstuffworks.com/earthquake4.htm

Body waves move through the inner part of Earth, while surface waves travel over the surface of Earth. Surface waves are responsible for most of the damage associated with earthquakes, because they cause the most intense vibrations. Surface waves stem from body waves that reach the surface.

There are two main types of body waves:

- **Primary waves**, also called **P waves** or **compressional waves**, travel about 1 to 5 miles per second (1.6 to 8 kps), depending on the material they're moving through. This speed is greater than the speed of other waves, so P waves arrive first at any surface location. They can travel through solid, liquid and gas, and so will pass completely through the body of Earth. As they travel through rock, the waves move tiny rock particles back and forth — pushing them apart and then back together — in line with the direction the wave is traveling.
(go to *http://web.ics.purdue.edu/~braile/edumod/waves/Pwave.gif* if you would like a visual of this). These waves typically arrive at the surface as an abrupt thud.

- **Secondary waves**, also called **S waves** or **shear waves**, lag a little behind the P waves. As these waves move, they displace rock particles outward, pushing them perpendicular to the path of the waves (go to *http://web.ics.purdue.edu/~braile/edumod/waves/Swave.gif* if you would like a visual of this). This results in the first period of rolling associated with earthquakes. Unlike P waves, S waves don't move straight through Earth. They only travel through solid material, and so are stopped at the liquid layer in Earth's core.

Both sorts of body waves do travel through the solid earth. Some can be detected on the opposite side of the planet from the point where the earthquake began. At any given moment, there are a number of very faint seismic waves moving all around the planet.

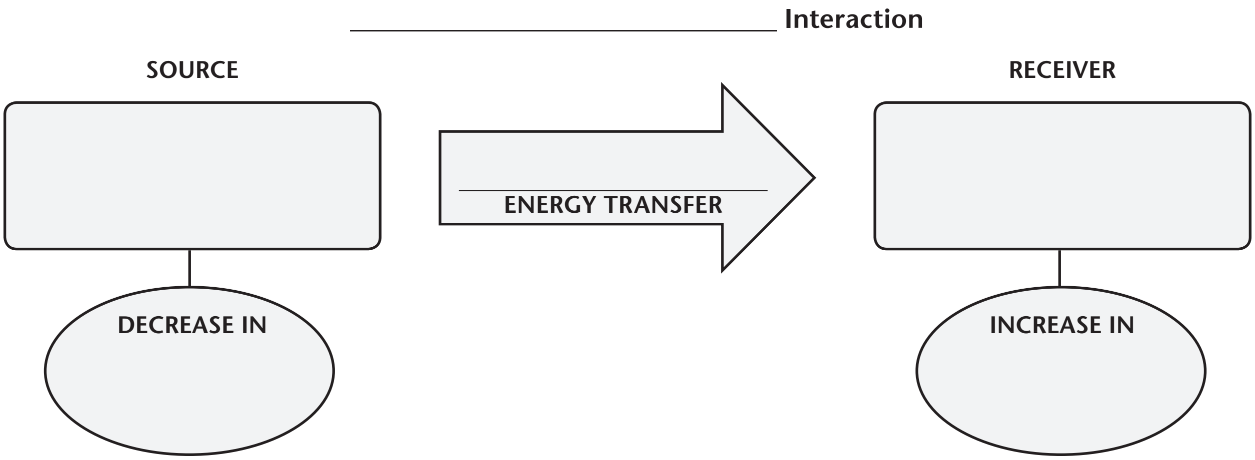
4. Go back to your drawings in 1 and 2 on the previous page and label which one represents a P wave and which one an S wave.

5. Given what you observed in the human wave analogy, do you predict that P and S waves travel at different speeds (use the results of your time trials)? Why or why not? Make sure to account for how these waves travel in your answer.

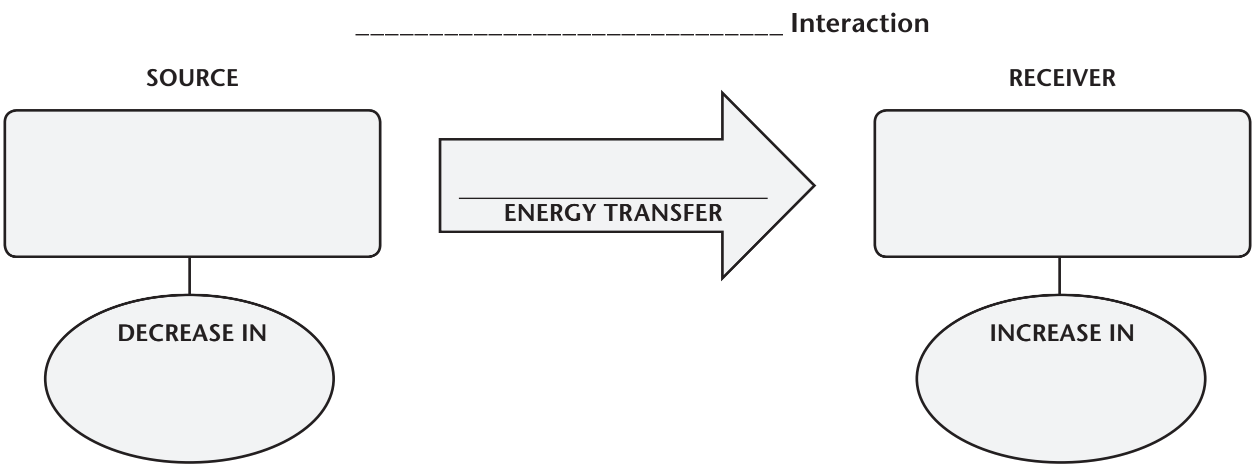
6. Given what you observed in the human wave analogy and in the reading, will P and S waves behave differently if they travel through liquid (molten) rock? Why or why not? (To check your answer, go to *http://www.classzone.com/books/earth_science/terc/content/investigations/es0402/es0402page03.cfm* to observe, yet again, another model that demonstrates this)

7. Write an explanation below for the interactions taking place in the Slinky and the type of energy transfer.

8. Draw an energy diagram (or several) showing how energy flows through the Slinky system from start to finish:



Explanation:



Explanation:

9. Relate this model and the waves you have generated to Earth. Are the energy transfers the same in the Slinky as in Earth? Why or why not?

Be sure to participate in the 5-Slinky block demonstration. Your classmates and the instructor will use the 5-Slinky block as a more sophisticated model of how earthquake (seismic) waves travel through Earth (as compared to a single Slinky). This model can help you visualize waves traveling in all directions from a point (e.g., an earthquake focus). Do your observations from the 5-Slinky block agree with what you learned from the single Slinky? Why or why not?

Discuss the answers to questions 5-9 in your group. Now, on your group's whiteboard, share with the class how you might be able to use earthquake (seismic) waves to discern what is in the interior of Earth (i.e., what is on the bottom of the cube)?

As you've seen in the last three Exercises, models are used regularly to simulate Earth processes. In what way is Earth Science different from Physics or Biology that might make it rely more on models such as these?

EXERCISE 4 *How do Earthquake waves travel through the Earth?*

Your instructor will set up a computer that will run Seismic Waves
(freeware from Alan Jones; *http://www.geol.binghamton.edu/faculty/jones/*)

When the animation starts, the user sees a 3-dimensional view of Earth in the lower left hand corner of the screen, a cross-sectional view of Earth in the lower right-hand corner, and a seismograph window at the top. A blast appears on the screen at the hypocenter along with a rumbling sound. The waves then begin to propagate through the earth and the seismograms develop. Each time a major component (P or S) a sound arrives at a station, a sound is heard.

This program is highly sophisticated and shows many additional waves that an earthquake causes besides the P, S, and Surface waves. Your instructor can explain how these different waves occur; alternatively, you can see if you can figure out some of these for yourself, looking at the screen on the lower right (hint: remember the black line in Cycle 5, Activity 1, Summary). You can also find out about these at *http://pubs.usgs.gov/gip/interior/*. For now don't get confused by these other waves, but just look for P, S, and Surface waves and ignore everything else.

1. At any given seismic station, which main type of wave arrives first (P, S, or Surface wave)? Which main wave arrives second? Does this agree with your prediction and your observation of Runs 1 and 2 in Exercise 2?

2. The further away from the earthquake, the greater the time lag between arrivals of the different waves. Why would this be true?

This delay will tell you how far away the seismic station is from the epicenter of the earthquake.

3. Notice the Earth in cross section on the right of your computer screen. As the program is running watch the wave types. What do you notice about the behavior of different types of waves as they cross the lines representing the earth's layers - inner core, outer core, and mantle? (Ignore PP, SS et al.)

4. Use your observations and the information from Exercise 2 and 3 of this activity to infer why the wave types behave differently through the different layers.

5. Given what you observe about how seismic waves travel in Earth's interior, is the Earth's mantle a liquid or a solid? How do you know?

Participate in a class discussion about your ideas.

SUMMARIZING QUESTIONS

1. Motion energy from plate movement is sometimes released by earthquakes, often dramatically. How are these earthquakes initiated?

2. Describe and illustrate how energy moves from the focus of an earthquake to a recording station that is miles away. Include at least two wave types by drawing the directions of wave propagation and the motion of a point along the wave's path (does this point move parallel or perpendicular or otherwise to the direction of the wave's propagation).

____

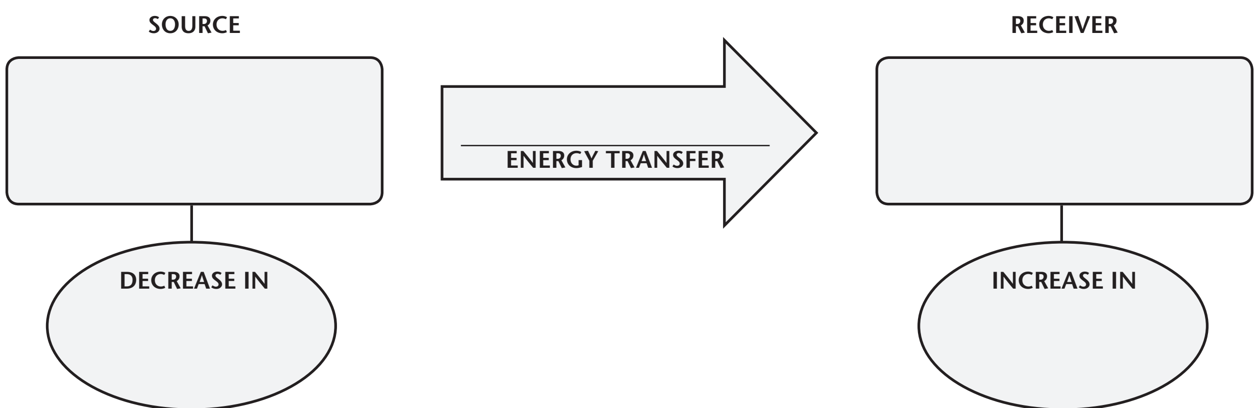
____

____

____

3. Complete the following energy diagram for an interaction in which energy from flowing solid mantle is transferred to rocks on the plates.

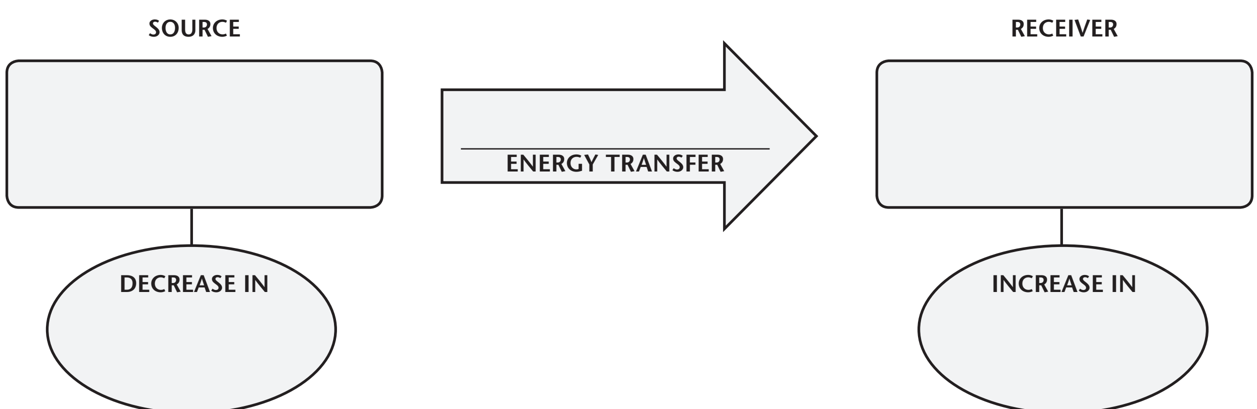
______________________________ Interaction



Explanation:

4. Complete the following energy diagram for an interaction in which energy from rock material is released (the rock breaks) and causes motion (the initiation of the earthquake wave motion).

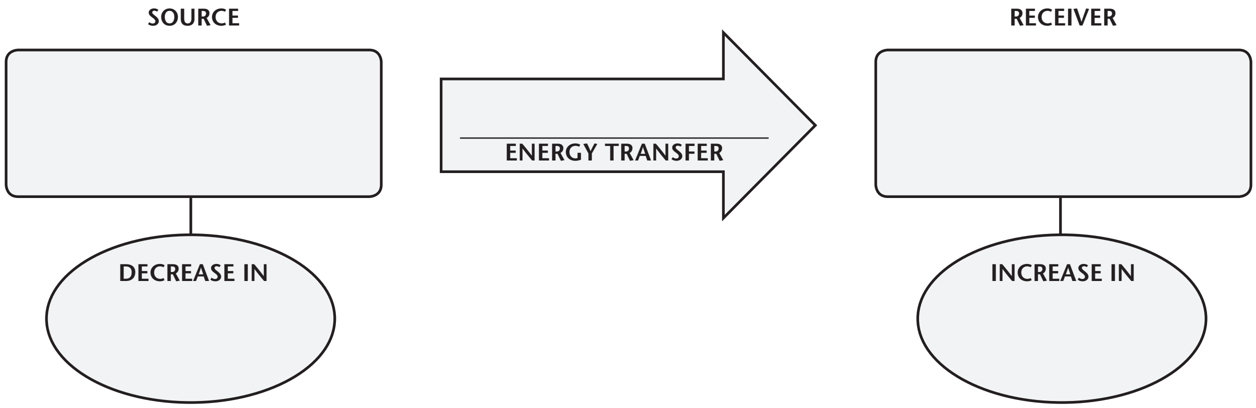
______________________________ Interaction



Explanation:

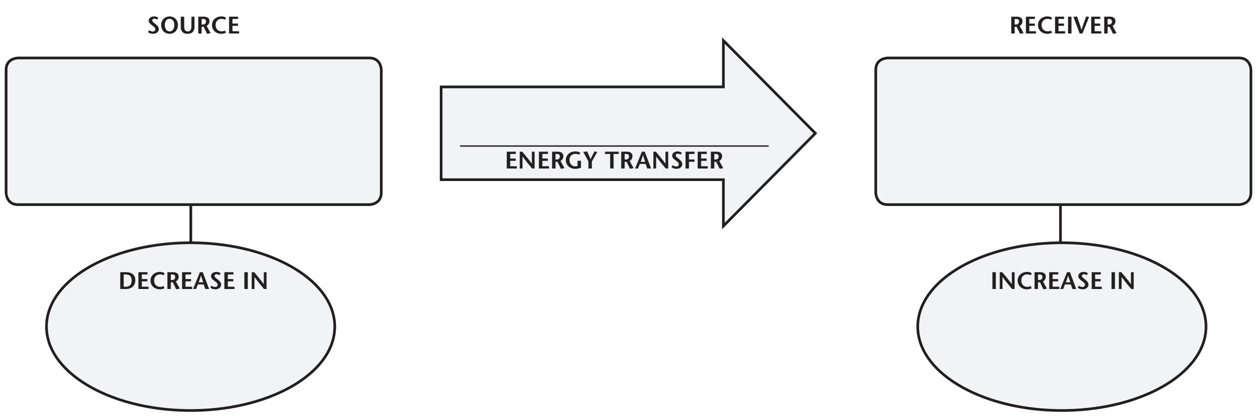
5. Complete the energy diagram below for an interaction in which energy is transferred between rocks as the earthquake wave travels.

______________________________ **Interaction**



6. Complete the energy diagram below for an interaction in which an earthquake wave topples a building.

______________________________**Interaction**



7. *If time is short, this question may be an optional exercise. Answer question 7 on the next page before beginning this question if you or your class is running behind.* Go to http://www.classzone.com/books/earth_science/terc/content/investigations/es0402/es0402page04.cfm?chapter_no=investigation in order to test your understanding of how scientists figure out what is inside Earth. This series of exercises shows seismic waves traveling through three fictitious planets.

   a) Based on the pattern of the P and S waves in this first planet, what type of material is this planet made of? How do you know?

   b) Click the "NEXT" button. Observe the pattern of P and S waves (you can move the slider back and forth to help you analyze the wave patterns). Sketch the layers below and indicate if they are solid or liquid.

c) Click the "NEXT" button again. Observe the pattern of P and S waves (you can move the slider back and forth to help you analyze the wave patterns). Sketch the layers below and indicate if they are solid or liquid.

d) Click the "NEXT" button for the final time. Compare the paths of P and S waves in models with liquid cores of different sizes. What happens to the size of the "shadow zone" (the area on the side of Earth opposite the earthquake that do not receive P or S waves) as the diameter of the liquid core increases?

8. Which parts of Earth's interior are molten? Which parts of Earth's interior are solid? How do you know?

9. If the outer core is molten, why isn't there a convection interaction between the outer core and the mantle?

Class Discussion

In your group, link the energy diagrams for questions 3-5 on your whiteboard. Be prepared to discuss how motion of the mantle may lead to the toppling of a building during an earthquake. Also be prepared to discuss the answer to question 7.

ACTIVITY 2: HOMEWORK

Name ______________________________ *Date*______________

FINAL REFLECTION

How have your ideas changed about where the energy of an earthquake comes from, how that energy is transferred inside Earth, and how that energy can be used to "see" what is inside Earth.

VIRTUAL EARTHQUAKE

Go to *http://vcourseware3.calstatela.edu/VirtualEarthquake/VQuakeExecute.html*

Select one of the 4 earthquakes to study and click the large submit button. Follow instructions all the way through and print the **certificate of completion** when you are finished. Attach your print-out to this page or if you can not print it, copy the information below:

Virtual Seismologist
Certificate of Completion

Name ______________________________

College ______________________________

City, State ______________________________

Date completed ______________

STATION	S-P INTERVAL		DISTANCE		AMPLITUDE		MAGNITUDE	
	YOURS	ACTUAL	YOURS	ACTUAL	YOURS	ACTUAL	YOURS	ACTUAL

ACTIVITY 3 *How does rock material behave inside Earth?*

PURPOSE

During your research, readings, and discussions you may have learned that Earth's interior is not molten (as many children believe). It is a hot solid that flows very slowly (cm/yr) like taffy, or silly putty.

Q. If the interior is not molten, where does the magma come from? What is the source of all that lava that is erupted at Mount Saint Helens or the Juan de Fuca Ridge or on the Big Island of Hawaii?

INITIAL IDEAS

1. From Cycle 4 recall the distribution of volcanoes on Earth's surface. What are some typical plate boundary types where volcanoes occur?

2. Based on Activity 1 of this cycle, how is the (solid but flowing) mantle moving at these different plate boundaries?

3. Combining your ideas from ideas 1 and 2, why do you think volcanoes occur at these different boundaries?

Lava, and all matter, is composed of molecules. Molecules are invisible to our eyes but are important to think about because they have a certain chemical composition and physical behavior. You may recall that we have used molecules to explain life processes in the biology segment of this course sequence. This physical behavior changes with different temperatures and pressures. In the next activity we will explore the change of behavior molecules experience.

Q. How does magma form and where does it come from?

WHOLE CLASS ACTIVITY: Six students from the class will volunteer to gather into a circle that has been drawn by the instructor. These students will pretend to be the molecules that make up rock in the Earth's mantle.

The instructor will secretly instruct the six student molecules how to "behave" in order to demonstrate what molecules would do in four different situations in the mantle. The rest of the class will try to interpret what the student *molecules* are representing. As a starting point the student *molecules* will stand still with arms locked and closely packed into a circle. This arrangement represents *molecules* of cool rock.

	Student *Molecule* Action	Possible Interpretation of Student *Molecules* Action
Step 1		
Step 2		
Step 3		
Step 4		

AS A CLASS: View the video clip of children's ideas on the source of magma

In your group discuss and record answers to the following six questions.

1. From your table, what are the difference in physical conditions (temperature, pressure, etc.) modeled by Steps 1 and 2?

2. What are the difference in physical conditions modeled by Steps 3 and 4?

3. How does this human analogy relate to how rock rises during mantle convection?

4. Why do we think that the mantle stays solid as it rises? If molten rock forms as mantle rock rises, where in the mantle does this melting probably occur?

5. Given what you just observed in this activity, how might volcanoes form at plate boundaries where plates move apart? Explain your reasoning.

6. Given what you just observed why do you think volcanoes are not so common in the middle of continents?

With your group, draw on your whiteboard a diagram that combines convection motion and molecular activity as explored in the student molecule analogy. Share your whiteboard and explain your diagram with the class. Discuss the relationship between changes in thermal energy, pressure, density, and molecular motion.

With the interpretation of the student molecule analogy, you now have a sense that rock can change from the solid state to the liquid state. From Cycle 4 we know that volcanoes are also found at locations besides divergent boundaries, so we still need to explore 'where do other magmas come from?' Before we go there, we will explore a household example of matter changing state, in this case water.

In your group discuss how water occurs as three states of matter around the house and record answers to the following four questions. Remember water in any state, like all matter, is composed of molecules.

≤ 0˚ C	0˚-100˚ C	≥ 100˚ C You can see the steam but not the gas.
		

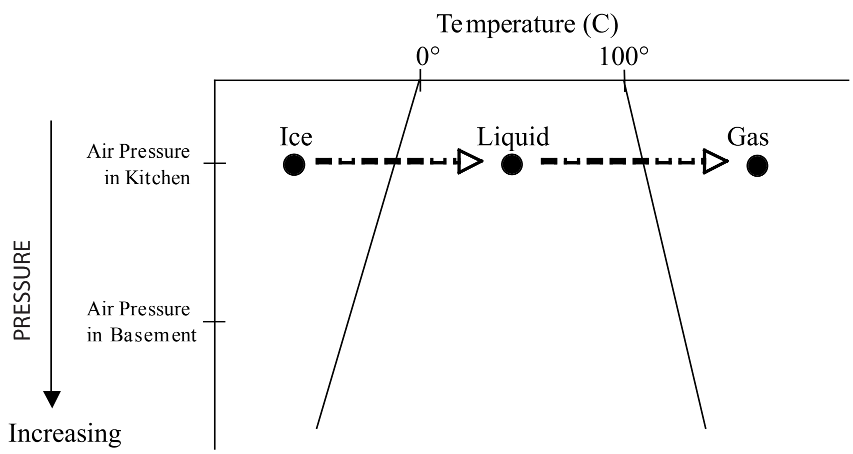
In which state are the molecules moving the fastest?

Which state has the greatest amount of thermal energy, which has the least?

Which has more thermal energy, the ice or the household air around the ice?

Without raising the temperature of an icecube above 0˚ C, can you think of any way to cause the ice to turn into water vapor ("sublimate")? Explain how, if this is possible (think about steps 3 and 4 in the last exercise).˚

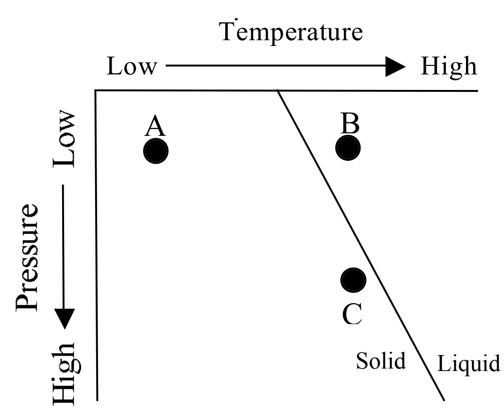
Scientists investigate how matter behaves at different conditions of temperature and pressure and they represent that behavior on a *graph*. Below is a graph that represents the "household" range of temperature and pressure that water experiences. Study and discuss this graph with your group. What conditions change in the direction of each arrow?



Under What Conditions Is a Material Solid or Liquid?

The graph below shows temperature and pressure under which a material is either solid or liquid. Temperature is plotted on the horizontal axis and pressure on the vertical axis.

The conditions for any place within Earth can be plotted as a point, like point A, that represents the temperature and pressure. Pressure is plotted as increasing from top to bottom on the graph to mimic the way pressures in Earth increase with depth. A diagonal line divides the graph into two fields (solid and liquid).



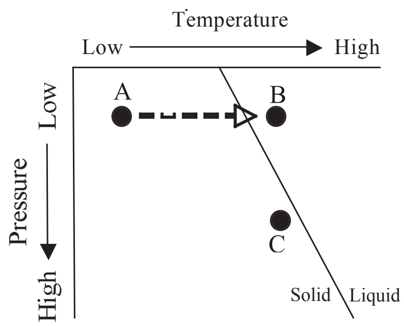
If a material is at conditions that plot to the left of the line (lower T) it is solid, like rock. If the conditions plot to the right (higher T) it is liquid, like magma.

Under What Conditions Do Rocks Melt?

There is more than one way to melt a rock. Rocks are poor conductors of thermal energy, therefore they do not lose or gain thermal energy quickly. A lot of heating is needed to melt rock. In the following group disscusion you will explore different conditions by which rock melts.

In your group discuss the next three graphs and record answers to the questions associated with each graph.

After studying this graph write out a statement that describes the relationship between increasing pressure, temperature and melting.



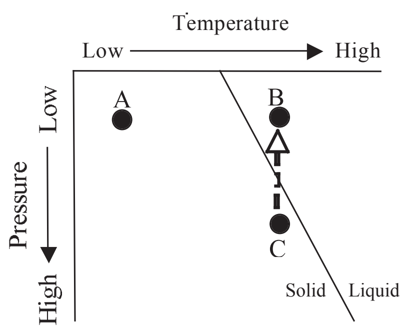
Rock at point A changes conditions as indicated by the arrow directed at point B. What conditions change and what happens to the rock?

What step(s) in the human molecule analogy correspond to the diagram from A to B?

Rock at point C is hotter than rock at point A. Why is rock at C still solid?

What step(s) in the human molecule analogy correspond to the change from C to B?

Rock at point C changes conditions as indicated by the arrow directed to point B.

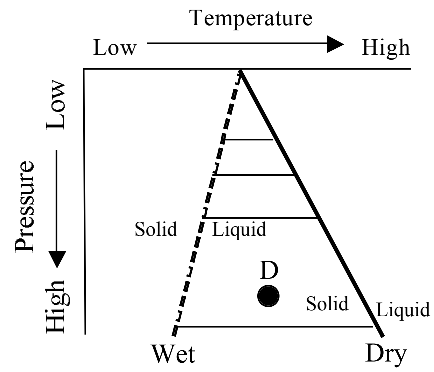


What conditions change and what happens to the rock?

Where inside Earth do you suppose that conditions can change in the way indicated by the arrow from point C to point B?

There is one other important way to promote melting. Think about an icy sidewalk on a cold (below 0˚ C) morning. Why do people spread salt on top of the ice? Can you think of other examples where a chemical lowers the melting temperature of a solid?

Rocks melt at a lower temperature when water is present. A dashed line indicates a solid-liquid line that shows the conditions of melting rock in the presence of water.



How does the presence of water change the melting temperature of rock?

If rock at point D was dry it would be solid. What can changed in order for rock at point D to melt?

At what type of plate boundary do you suppose that water could be added to rock deep in the mantle?

Where Does Melting Occur?

Thermal energy is most abundant in the core of Earth. Scientists infer that some of this thermal energy causes parts of the deep mantle to heat up and rise. At certain types of plate boundaries, melting of the shallow mantle occurs. This shallow melting is what we want to relate to the solid-liquid graphs we have just studied.

In your group discuss melting at plate boundaries with the block diagrams and answer the following questions.

At a divergent plate boundary you have learned that two plates move apart. As this motion occurs the plate (the thickness of the lithosphere) moves across part of the mantle, known as the asthenosphere. At the same location, rising from the deep mantle, hot and solid mantle rock is rising toward the upper mantle.

1. Infer what happens to the rock of the upper mantle when the plates move apart, and the deep mantle rock rises to fill the void.

At a convergent plate boundary with a subduction zone, an oceanic plate, composed of oceanic crust and the uppermost mantle, subduct into the mantle. Because, the top of the oceanic crust was formally the ocean floor, the crust also brings water and sediments into the subduction zone.

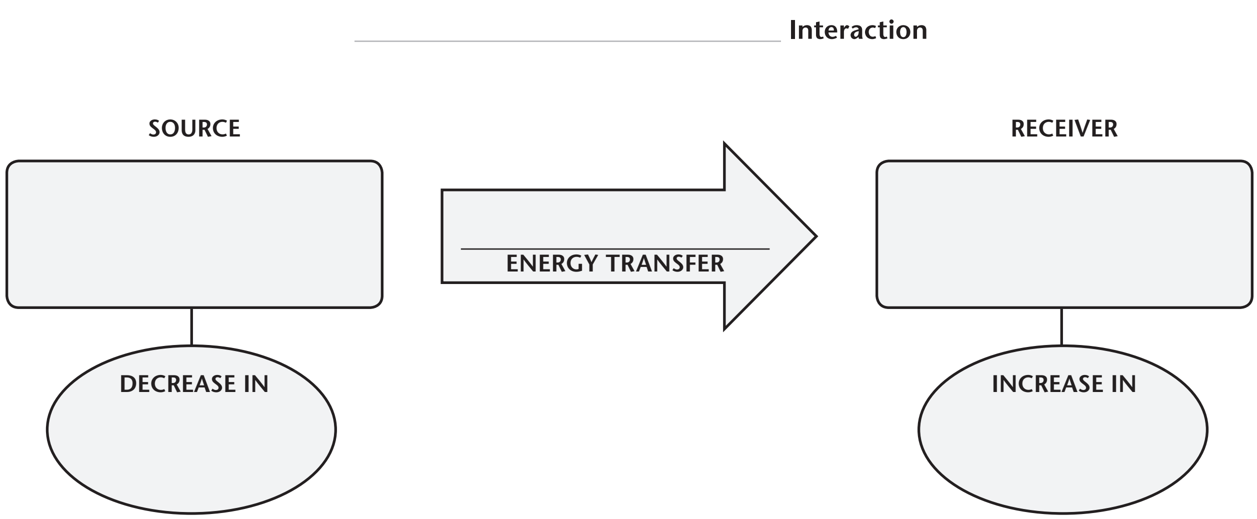
2. Infer what happens when the oceanic plate, with water, is subducted and exposed to the heat of the mantle.

3. In Cycle 4 you observed the spatial relationship between ocean trenches that occured close to and parallel to chains of volcanoes. Infer the relationship between the ocean floor features, the volcanoes, and the location of melting.

View the video of children responding to the question "If you could slice through the Earth what could it look like?"

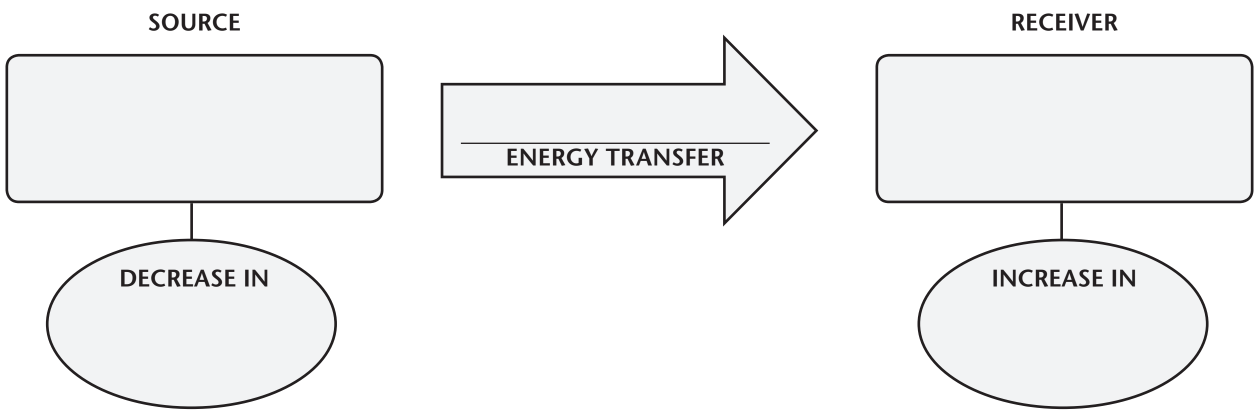
SUMMARIZING QUESTIONS

1. Create an energy diagram to represent the decompression melting that occurs at divergent plate boundaries. If this is not possible, explain why not.



2. Complete the energy diagrams below to show the energy exchanges that occurs when lava pours out of a volcano. If your group needs more energy diagrams to complete describe this process, feel free to use more.

_____________________________ **Interaction**



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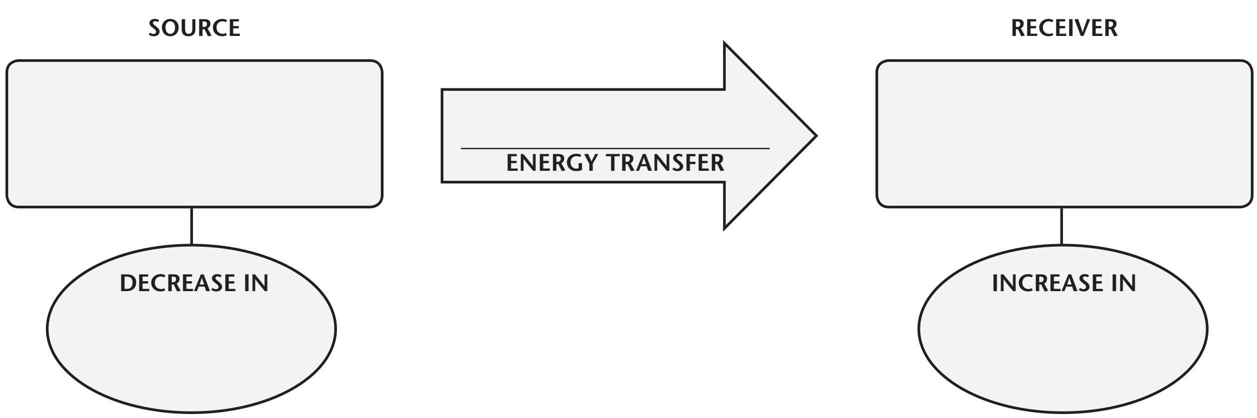

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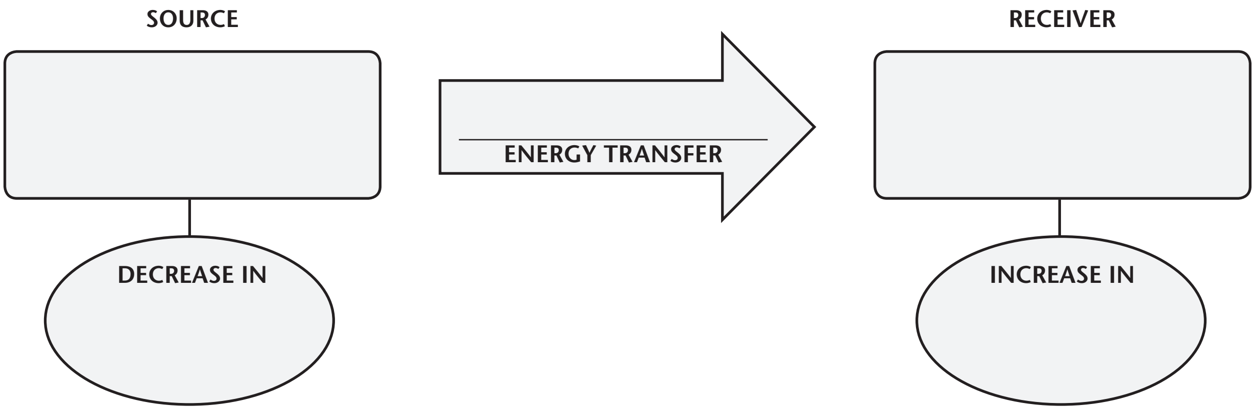
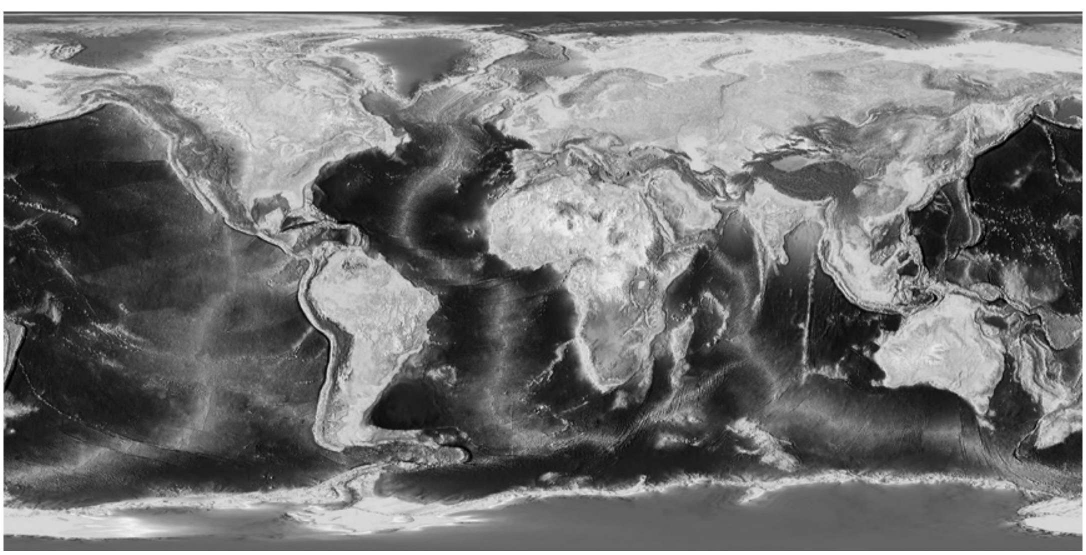


Draw your energy diagrams on a whiteboard and be prepared to share them with the class.

CYCLE 6

How does energy and matter flow in Earth Systems?



CYCLE 6

How does energy and matter flow in Earth Systems?

OVERVIEW

In this final cycle you will take all the different energy flow diagrams that you have created and try to put them together into a cohesive, integrated view of how Earth systems work and interact. You will take your existing energy diagrams and attempt to link them together (and perhaps generate new diagrams to fill in gaps) as you describe: the mass and energy transfers that occur as the heat generated by the radioactive decay of a single potassium atom in Earth's core makes its way to the vacuum of deep space.

ACTIVITY 1 *Review and synthesis*

PURPOSE

We have studied many different processes and systems during this course. In this cycle, you will reacquaint yourselves with the Earth systems we have studied, beginning in Cycle 4. After you have compiled a record of the energy diagrams of Earth systems studied so far, you will try to connect the energy processes and systems into an integrated view of the Earth. We will also look at the movement of mass inside and between systems and see how that relates to energy flow.

COLLECTING DATA

YOU WILL NEED:

- a pad of large 4″ x 4″ or 4″ x 6″ Post-It notes
- a pad of small (2″ x 2″) Post-It notes (one unique color per team)
- dry erase markers (black, blue, and red)
- one large mural (cross-section and surface) for each team
- teams of 4-6 students

BEFORE BEGINNING THIS ACTIVITY

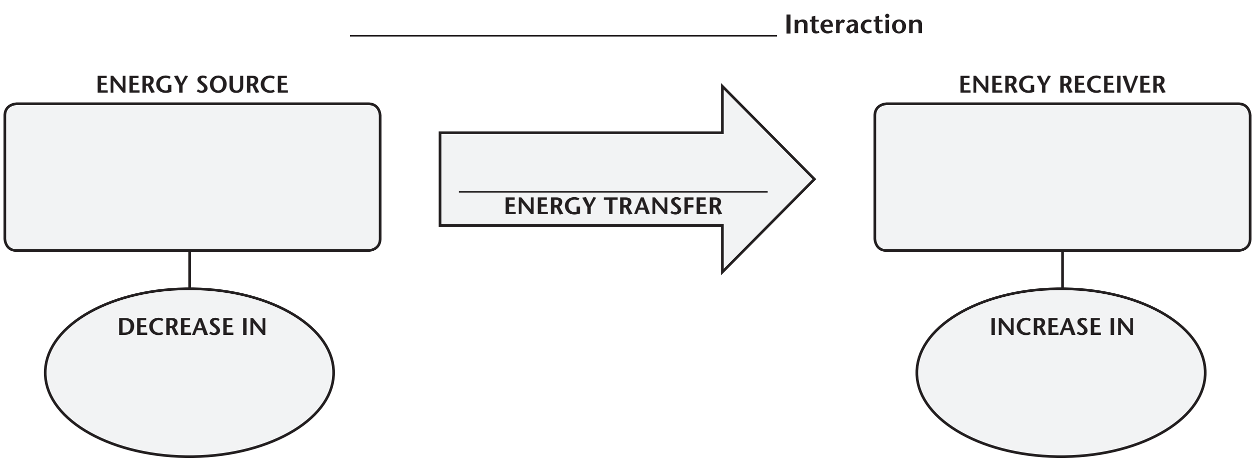
By yourself, use the following table of energy diagram templates to compile all the energy diagrams/processes that you have worked on over the term of this course. It may help to start near the beginning of your notebook and quickly leaf through the different activities to refresh your memory. You can edit old diagrams to incorporate new ideas or vocabulary that you have developed over the duration of the course, but be sure that you have a diagram for all processes we have studied since Cycle 2.

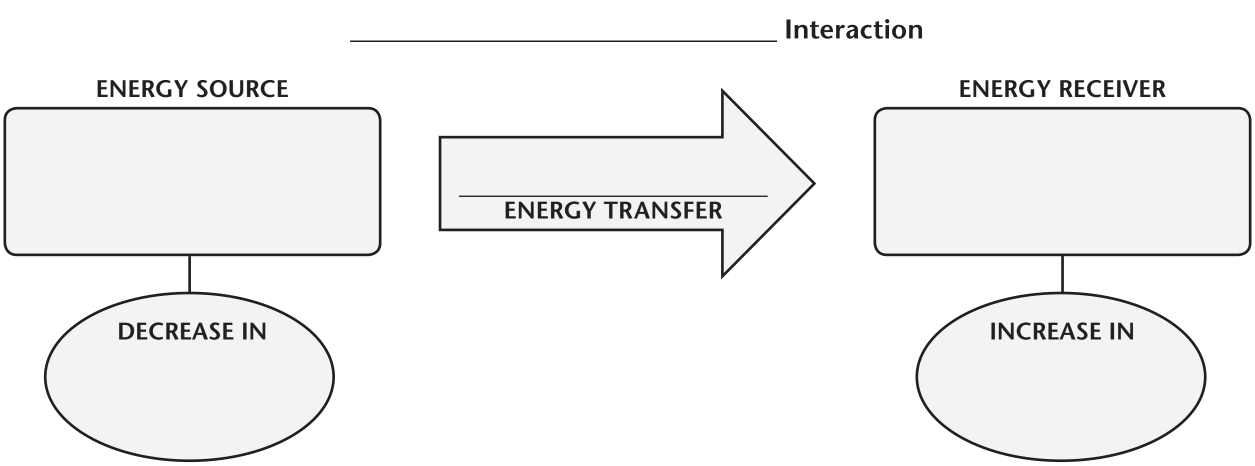
Remember to focus in on energy transfers that occur as heat is generated by the radioactive decay of a potassium atom in Earth's core, and as this heat makes its way to the vacuum of deep space. *You should be able to draw at least 20 diagrams describing Earth processes involved as the heat from the potassium atom moves from the core out toward space. Be sure to use our standard templates, as provided on the following pages..*

STEP 1 (~20 MINUTES)

Within your team, compare all the energy diagrams/processes that you and your group partners have prepared above. It may help to go through these chronologically (in the order they were developed in the notebook) or by topic (for example, energy transfers for earthquakes or convection). As you complete your compilation, make a note of where these processes occur; for example, does the energy diagram describe something that happens deep in the Earth, or only on the surface, in the oceans, or elsewhere?

As a group, come up with the best collection of energy diagrams for as many processes as you can. If necessary, feel free to construct new diagrams to fill in any gaps or expand on some step in a process. Using the Energy Interaction Type table (on the wall and in Cycle 4) may help resolve questions of what kind of energy transfer has occurred. *Your group should be able to draw at least 20 diagrams describing Earth processes.*





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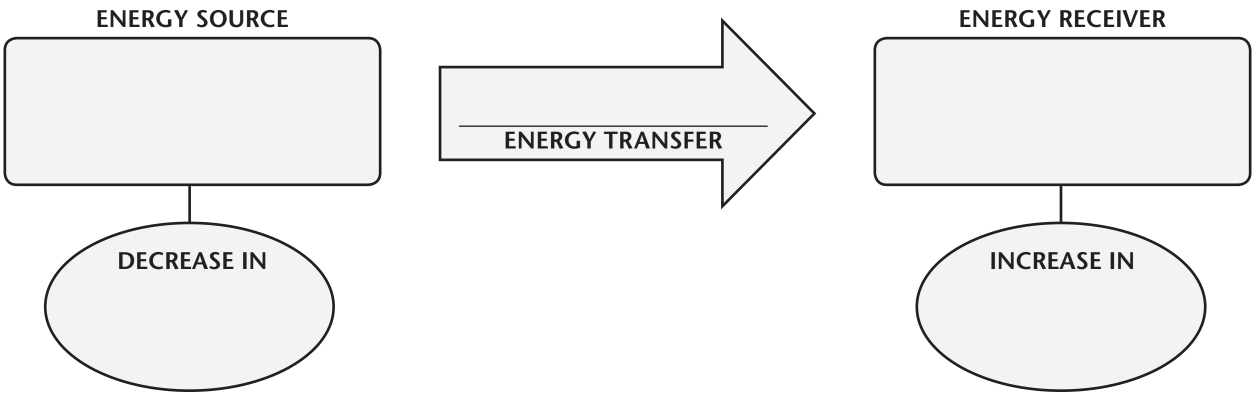

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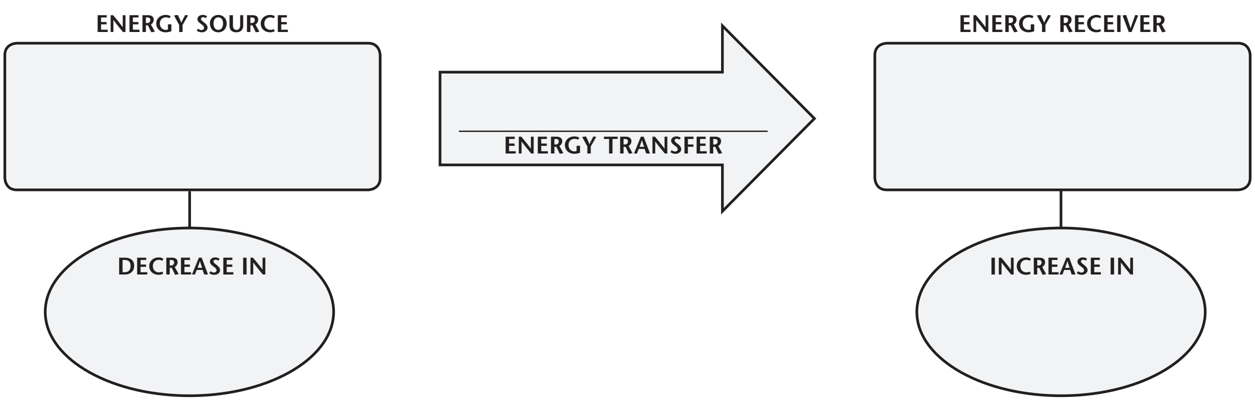

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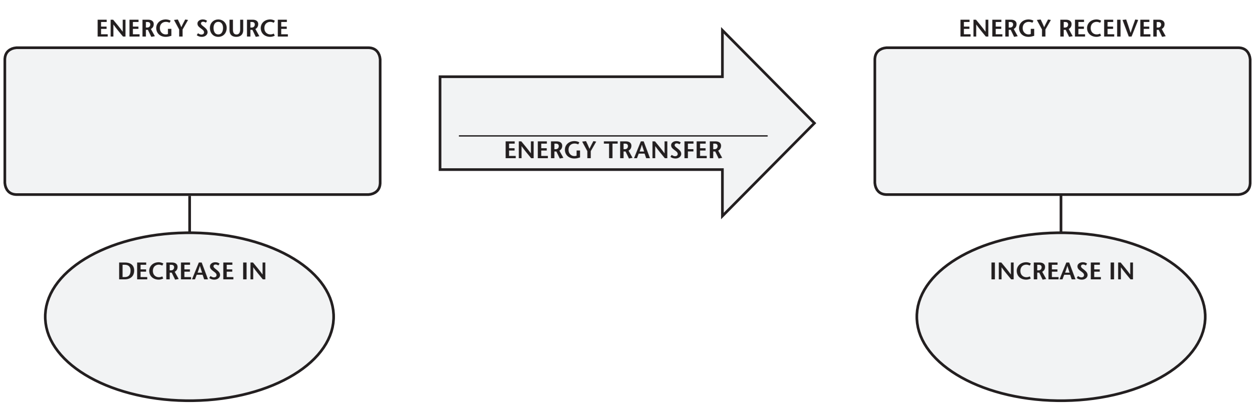

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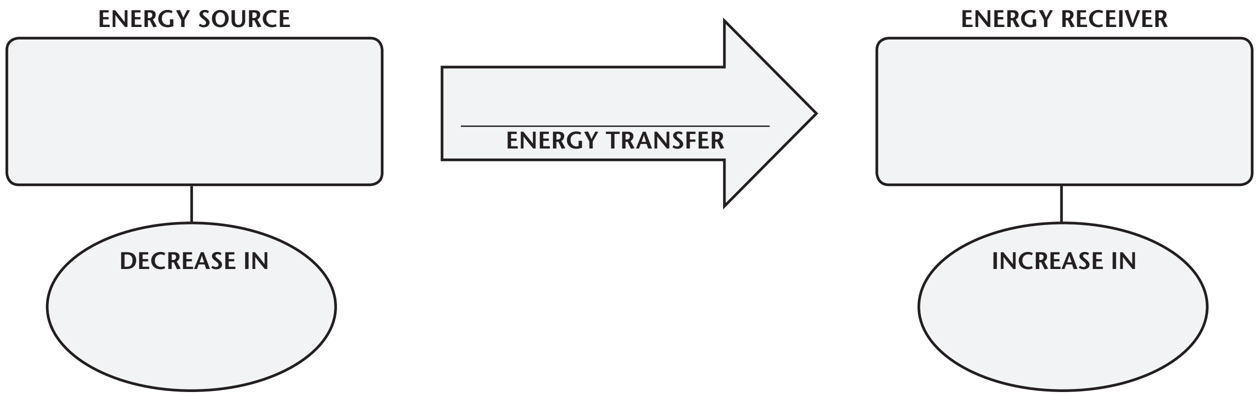

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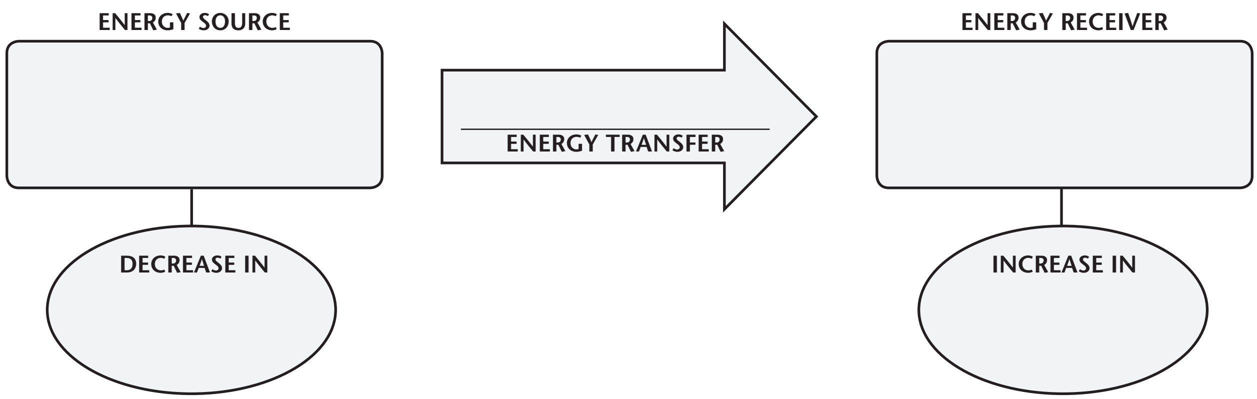

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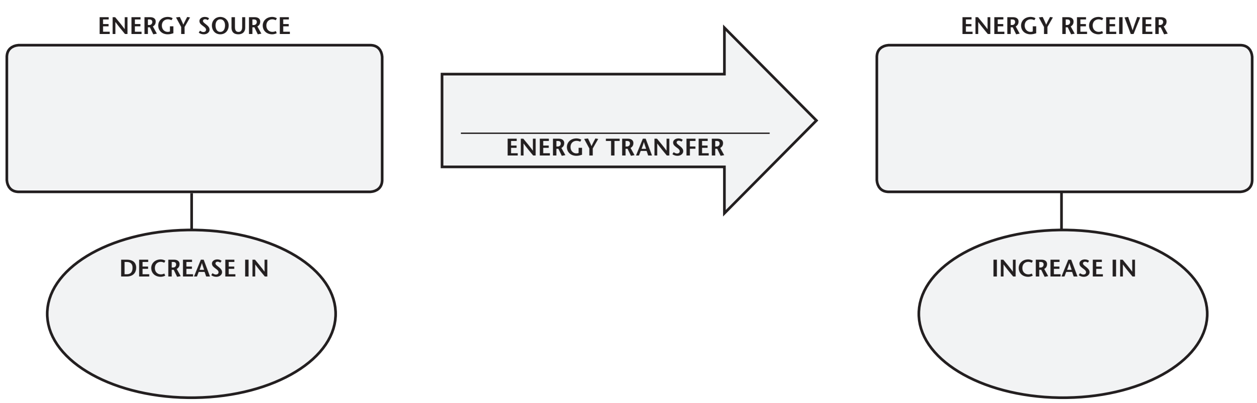

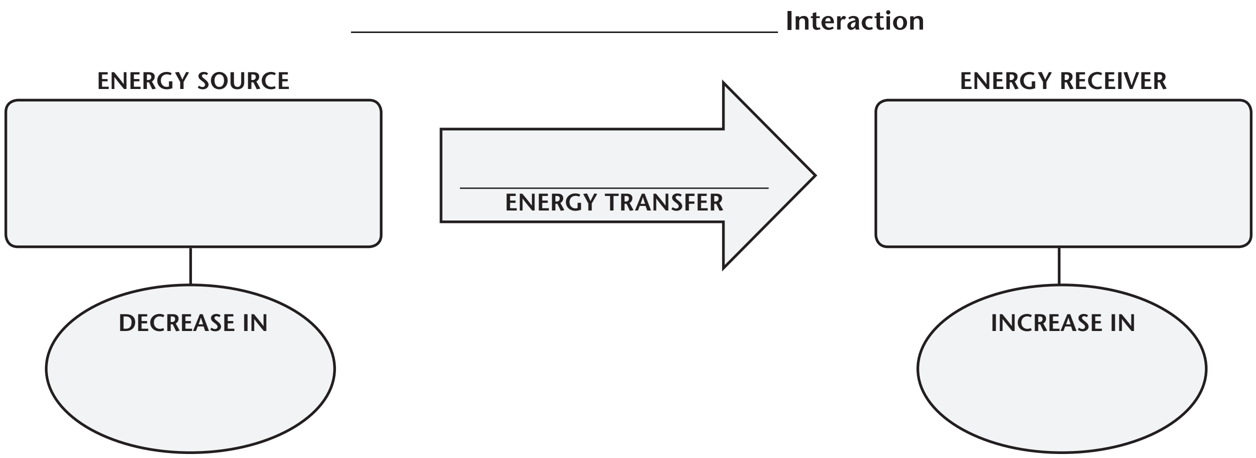
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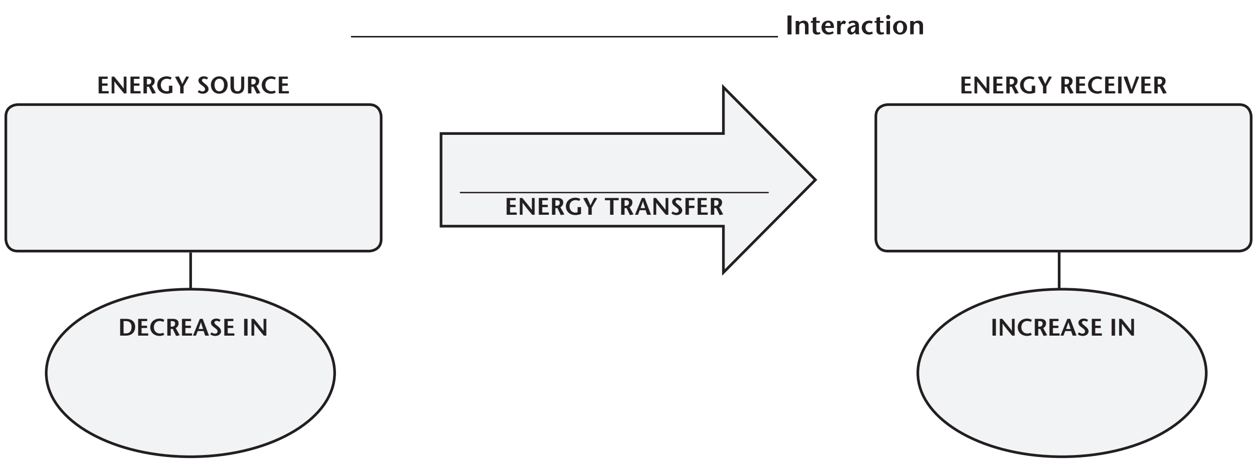
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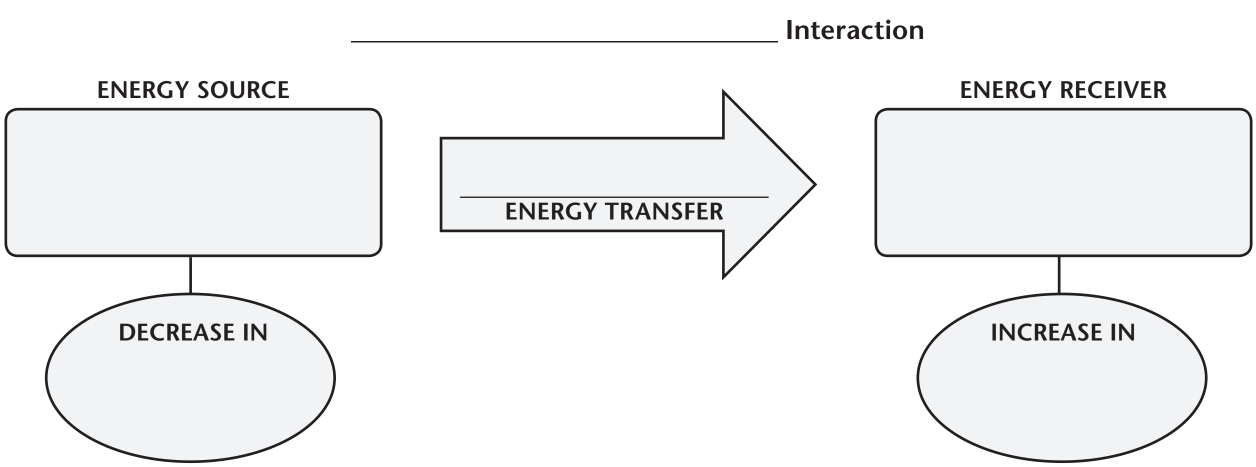
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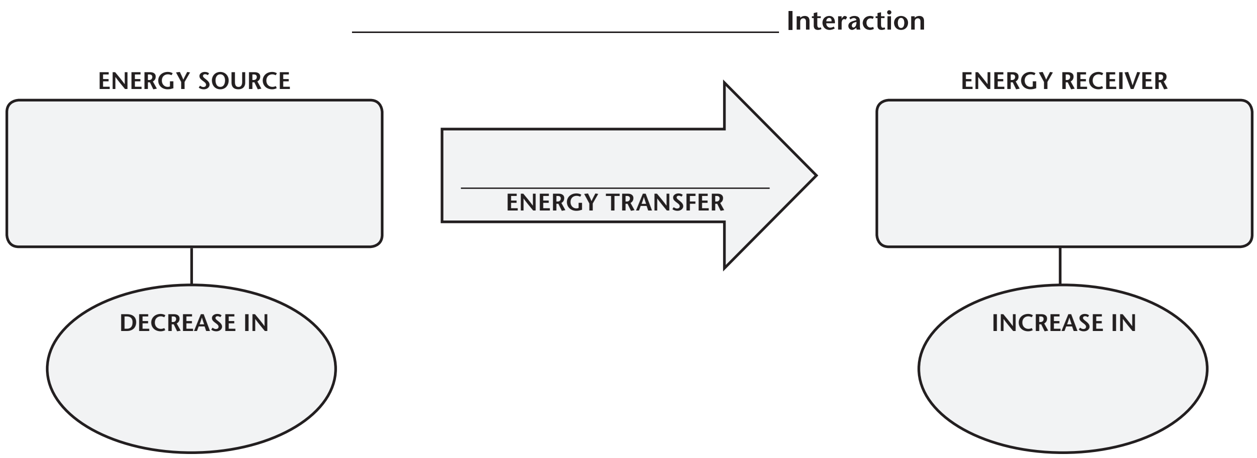
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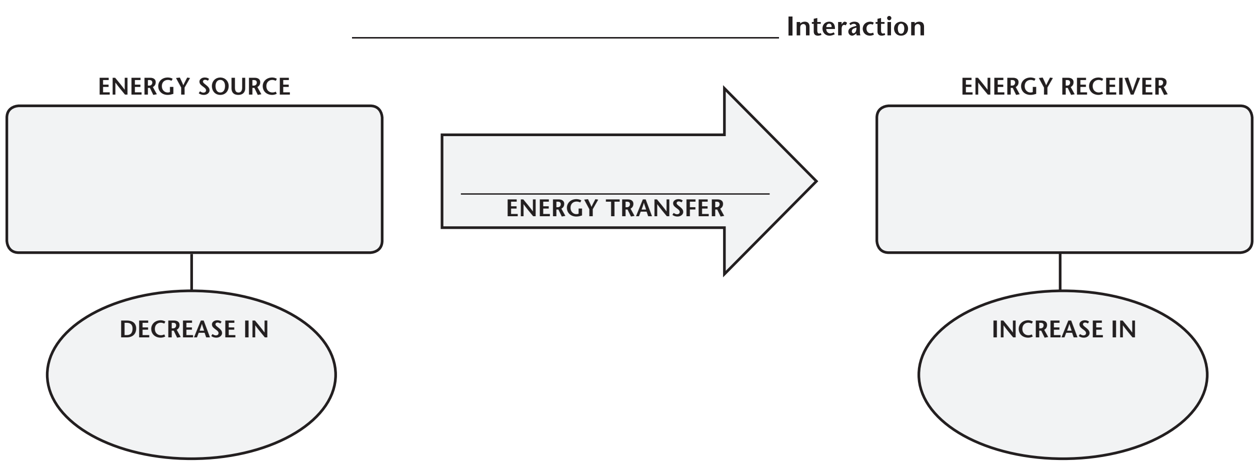
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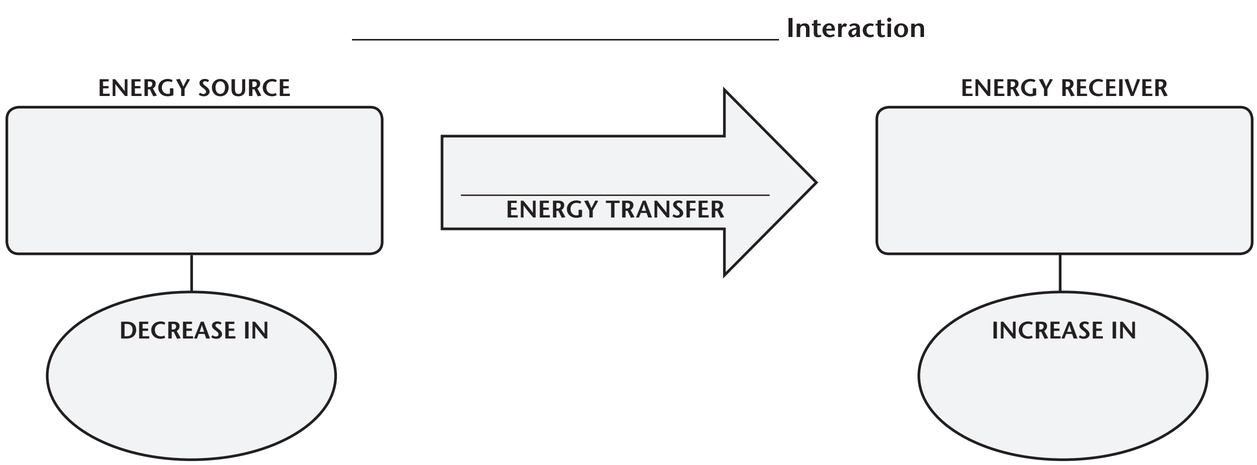
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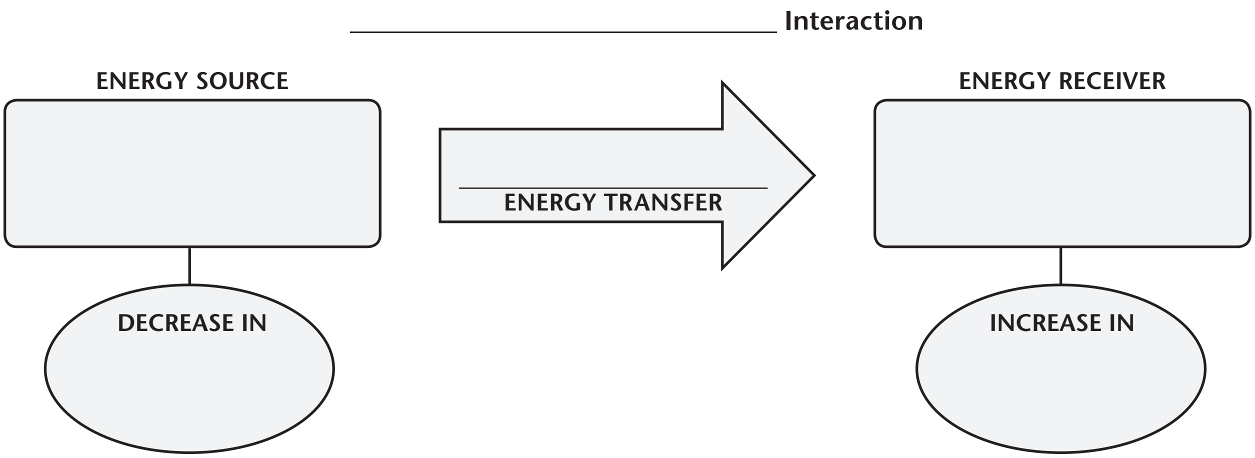
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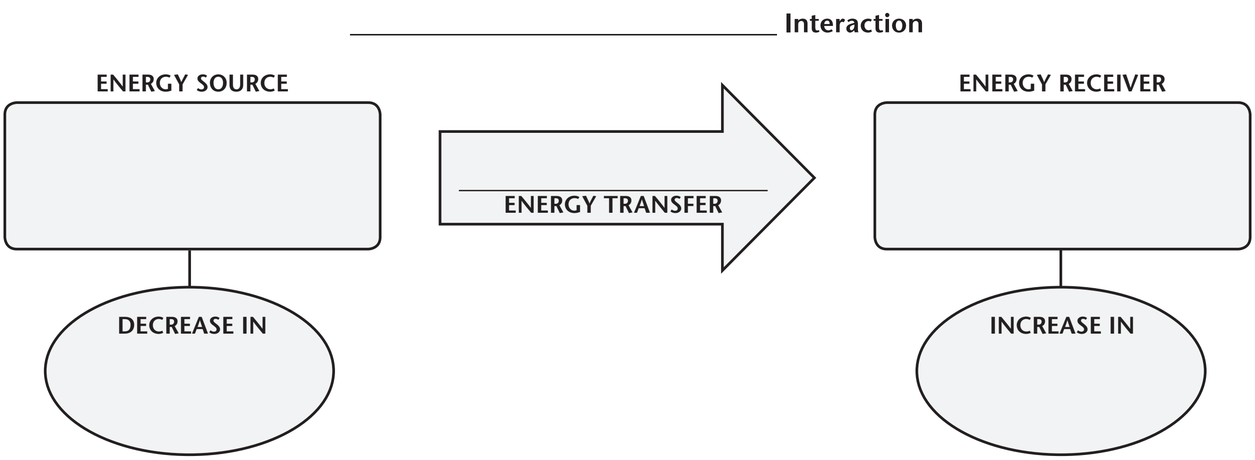
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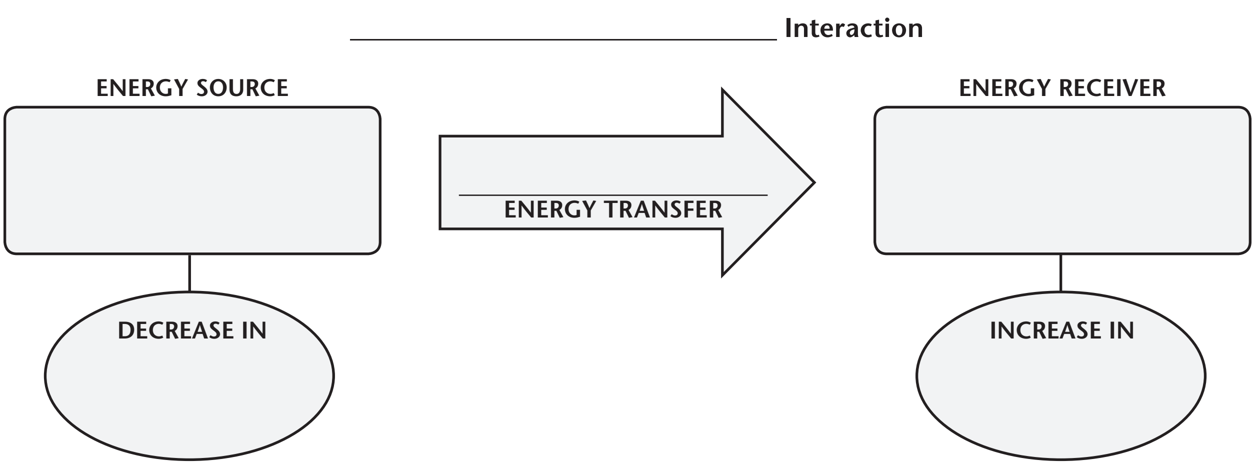
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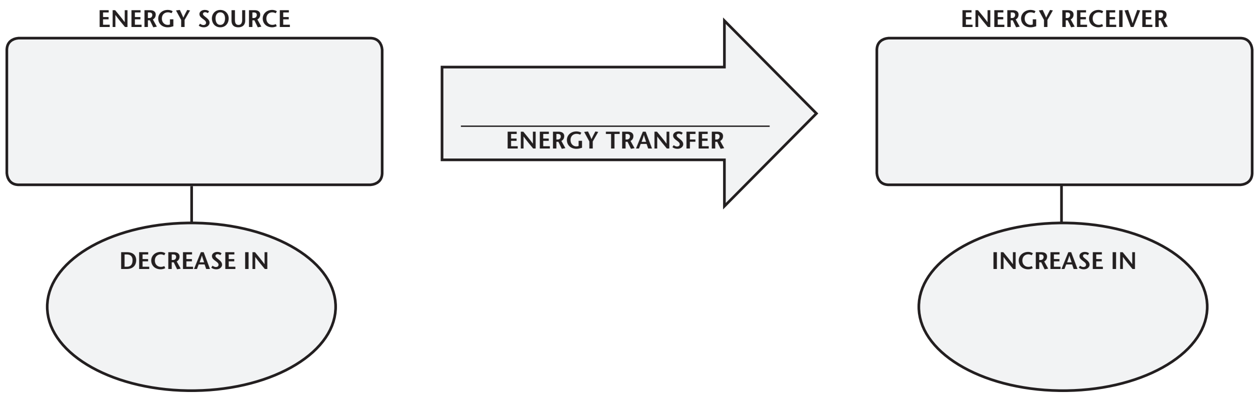

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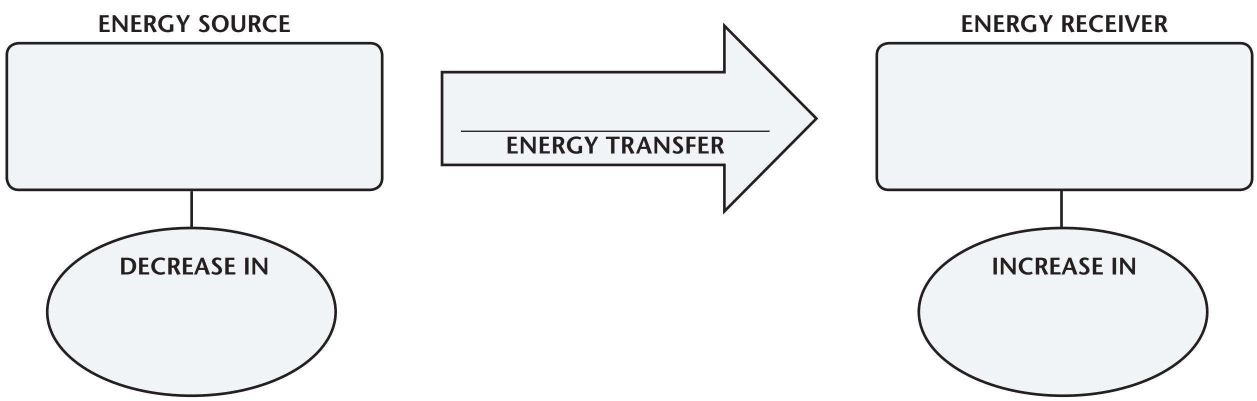

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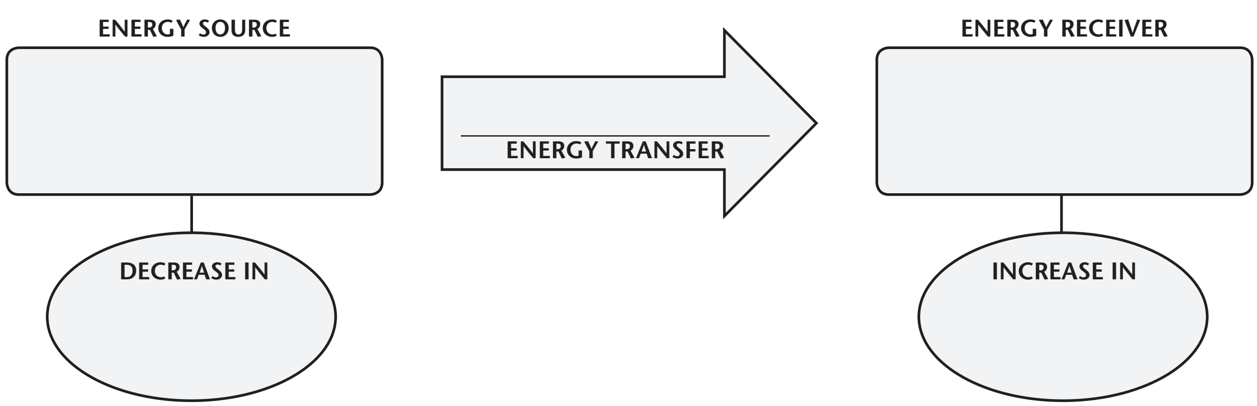


After your group tallies all the natural Earth processes that have been diagrammed during this course, your team should begin to copy these diagrams onto your large Post-It notes. Be sure to draw only one diagram on each Post-It. Also, do not put up duplicates of different steps; do your best to reach a consensus in your team on how to uniquely diagram each step of the process that your group is describing.

STEP 2 (~20 MINUTES)

Place your Post-It notes of the energy diagrams on your group's large mural in the region that your energy diagram describes. Also place a large Post-It note with your group's number prominently displayed in the upper right corner of the mural. Be sure your diagrams are easily visible - do not overlap them or bunch them up.

At this point you can also add new energy diagrams (with Post-It notes) that we have not previously considered to describe processes of Earth systems to make your mural more complete or comprehensive. Use the same format that we have used for all of our energy diagrams, and be very clear what process you are describing.

STEP 3 (~15 MINUTES)

With the red and blue dry erase pens, use arrows or other symbols to show how **mass** moves in each process. For example, you may show arrows for sediments moving downstream, or for the flow of the mantle. IMPORTANT: Use the blue pen for observed mass movements and use the red pen for inferred mass movements.

Try your best to indicate any links you see between energy diagrams and the motion of mass.

When you are done with your two murals, mount them on the classroom walls so everyone in the class can study them.

SUMMARIZING QUESTIONS

1. (~20 minutes) Study the mural of the team next to you. Carefully note on Table 6-2 how their energy diagrams and processes are similar to yours, and how they differ. Use your group's small Post-It notes (different color than the other team's) to ask questions of the other team or make comments on their mural.

TABLE 6-2

GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP ________ ANALYSIS (DIFFERENCES)
GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP ________ ANALYSIS (DIFFERENCES)
GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP ________ ANALYSIS (DIFFERENCES)
GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP _______ ANALYSIS (DIFFERENCES)
GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP ________ ANALYSIS (DIFFERENCES)
GROUP ________ ANALYSIS (SIMILARITIES TO OURS)	GROUP ________ ANALYSIS (DIFFERENCES)

Next, look at their mass movement arrows. Again, does this team have mass movements that your team did not have, or are they missing some that your team found? List the similarities and differences on Table 6-2, and again use the small Post-It notes to ask questions or make comments on the murals.

Finally, check to see if their inferences compared to observations of mass movement are similar to your team's ideas.

2. Repeat #1 for all the teams in your class, ($\leq$ 10 minutes per team). Be sure to add questions or comments on the murals as you go along. Also, add your results to Table 6-2 until you have studied every team's murals.

3. After you have studied every team's murals, go back to your team's murals. Collect the questions and comments that your classmates have posted, and discuss these notes as a team. Make any changes to your murals or energy diagrams to clarify or resolve issues raised by other teams' comments or questions, and be ready to discuss how you think energy and matter flows in Earth systems using your murals.

Group Discussion

Share your ideas of how energy and matter move within and across Earth systems with the whole class. Use your murals like a giant whiteboard to illustrate your ideas. As part of your discussion, describe which systems or processes you would like to have learned more about, and which one(s) your team is still a bit uncertain about.

MORE SOURCES ABOUT MISCONCEPTIONS ABOUT EARTH SCIENCE

Print Resources for Earth Science Misconceptions

1. Bisard, W. J. et al., 1994. Assessing selected physical science and earth science misconceptions of middle school through university pre-service teachers. *Journal of College Science Teaching, v. 24, p. 38.*

2. King, C. 2000. The Earth's Mantle Is Solid: Teachers' Misconceptions About the Earth and Plate Tectonics. School Science Review; v82 n298 p57-64. The study focuses on common misconceptions held by teachers.

3. Marques, L. and Thompson, D. 1997. Misconceptions and Conceptual Changes Concerning Continental Drift and Plate Tectonics among Portuguese Students Aged 16-17. Research in Science and Technological Education; v15 n2 p195-222. A teacher-learner model is suggested for countering misconceptions associated with plate tectonics.

4. Philips, W. 1991. Earth Science Misconceptions, Science Teacher; v58 n2 p21-23. The article lists over 50 misconceptions, categorized by age level, for various earth science topics.

5. Taylor, I. 1996. Illuminating Lunar Phases. Science Teacher; v63 n8 p39-41. The article uses a constructivist approach to address misconceptions concerning the moon.

6. Trend, R. 2001. Deep Time Framework: A Preliminary Study of U.K. Primary Teachers' Conceptions of Geological Time and Perceptions of Geoscience. Journal of Research in Science Teaching; v38 n2 p191-221. In-service teachers act as a study sample to identify misconceptions associated with earth science phenomena in general and deep time in particular.

Web Resources for Earth Science Misconceptions

1. Fraser, A. 2000. *Bad Meteorology* (more info) http://www.ems.psu.edu/~fraser/BadMeteorology.html, accessed 15 November 2004. Find discussion relating to cloud formation, raindrop shop, greenhouse effect, and Coriolis Effect.

2. Henriques, L. 2000. *Children's misconceptions about weather: A review of the literature* http://www.csulb.edu/~lhenriqu/NARST2000.htm, accessed 15 November 2004. A tabular presentation of misconceptions relating to the water cycle, phase changes, clouds, precipitation, atmosphere, seasons, heating of the earth, and greenhouse effect. An extensive bibliography accompanies the article.

3. Lehmann, K. 2000. *Bad Chemistry* http://www.princeton.edu/~lehmann/BadChemistry.html, accessed 15 November 2004. The hydrophobic effect, pressure melting, and ionic solutions are mentioned as causes of frequent misunderstanding.

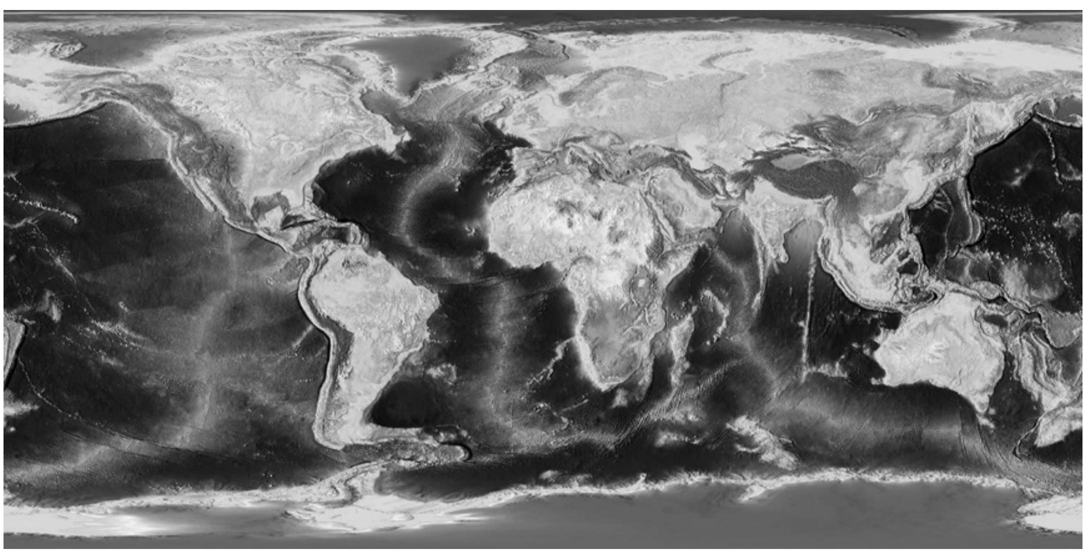
4. Maine Mathematics and Science Alliance, 2002. *Sampler of Common Identified Misconceptions or Alternative Ideas Linked to Earth and Space Science Concepts in Maine Learning Results* http://www.nasalearn.org/teacher_support_alerts_misconceps_earthsci.htm, accessed 15 November 2004. The site classifies particular misconceptions (geologic time and change, seasons, rocks, water cycle, phases of the moon, scale, and gravity) with National Science Standards. References are lacking.

5. National Research Council, 1997. *Misconceptions as Barriers to Understanding Science,* http://bob.nap.edu/readingroom/books/str/4.html, accessed 15 November 2004. Chapter four of "Science Teaching Reconsidered", assesses the role of misconceptions in the learning process, descriptions and examples of some common misconceptions in science, methods to identify misconceptions, and methods to break down misconceptions.

6. Phillips, W. 1991. *Earth Science Misconceptions,* http://k12s.phast.umass.edu/~nasa/misconceptions.html, accessed 15 November 2004. Find a variety of misconceptions categorized by age level as well as subject.

7. Plait, B. 2004. *Bad Astronomy Misconceptions,* http://www.badastronomy.com/bad/misc/index.html, accessed 15 November 2004. Bill Plait discusses a variety of celestial misconceptions ranging from the moon landing hoax to the cause of the seasons.

Supplemental Section



ACTIVITY 1: HOMEWORK

Name ______________________________ *Date*____________________

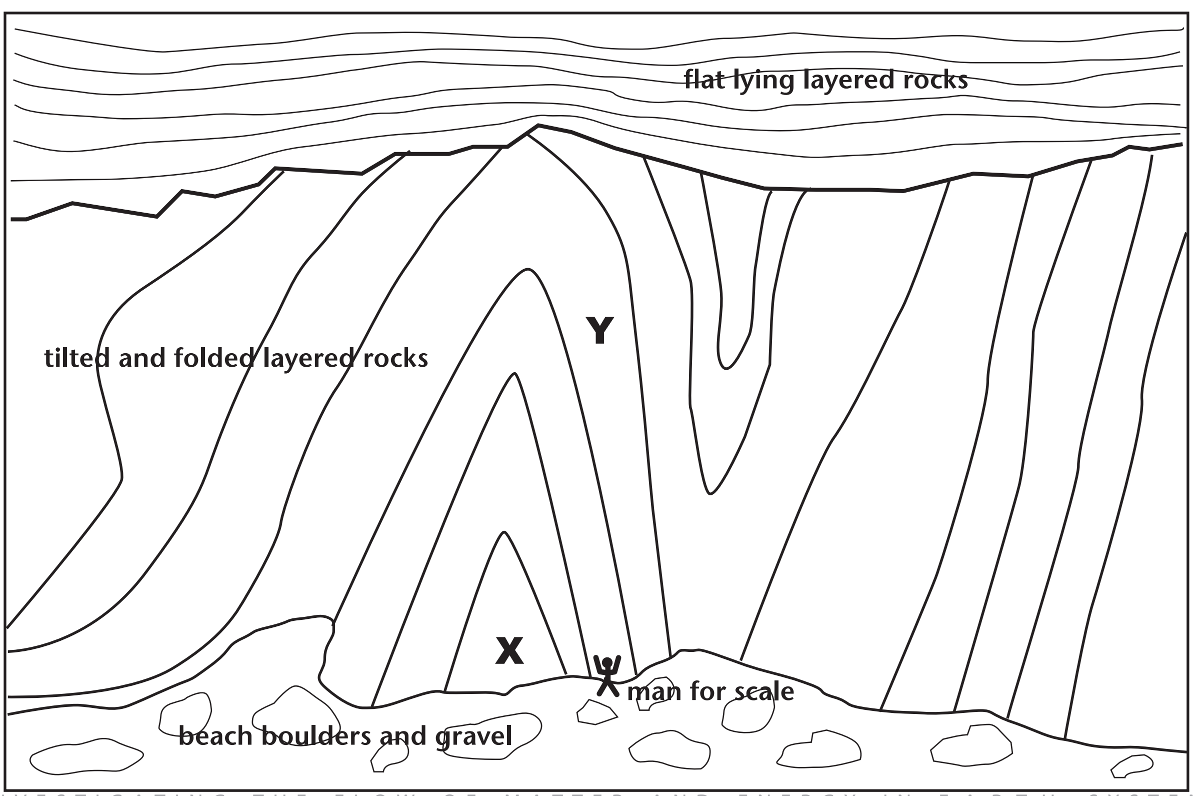
How do we know that Earth has changed over time?
Can Earth be "read" like an open book?
Can a geologic history of an area be inferred by looking at rocks?

INITIAL IDEAS
Have you ever noticed layers of rock exposed in a beach cliff? In a road cut? In a canyon cut by a river? Make a sketch and describe what you saw.

A. This is a photograph of sedimentary rock layers that are exposed in a beach cliff.

Source: http://www.globalchange.umich.edu/Ben/Tr%20unconformity.JPG

B. This is a sketch that shows the layers of rock and their relationship to each other



In Cycles 1 and 2 you practiced making observations and making inferences from your observations. Now apply your skills to looking at rock layers in Earth.

STEP 1: OBSERVE THE PHOTOGRAPH ON THE PREVIOUS PAGE
What do you observe about the layers that you see in the photograph? In the observation column below, write down and describe, at least 5 different observations for the rock layers that you see.

STEP 2: MAKING INFERENCES FROM YOUR OBSERVATIONS
For each observation you made, think of an inference that you can make about that observation. Write your inferences in the Inference column. Be sure to **describe your reasoning** for each inference that you make. See example.

STEP 1 OBSERVATIONS	STEP 2 INFERENCES
EXAMPLE Layer X is lower than Layer Y	Layer X is older than layer Y. Reasoning: you know that when you deal out playing cards, the first card dealt (oldest) will be lower than the cards that lie on top (younger).

STEP 3: RELATIVE AGE DATING

Using your observations and inferences, do your best to list the rock units in the chronologic order in which they formed. List the order from oldest to youngest. Include flat lying layered rocks, Layer Y, Layer X and beach boulders + gravel.

SCIENTISTS' IDEAS ABOUT RELATIVE AGE DATING

PART A

Go to the U.S. Geological Survey websites, resources for Scientists' Ideas about Relative Age Dating. Use this information for Part B.

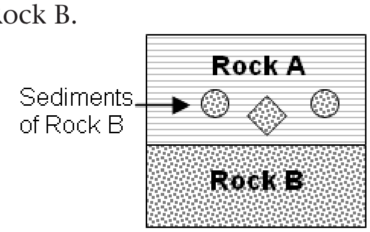
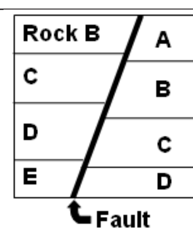
Fossils, Rocks, and Time by Lucy E. Edwards and John Pojeta, Jr.
http://pubs.usgs.gov/gip/fossils/contents.html

Geologic Time by William L. Newman
http://pubs.usgs.gov/gip/geotime/contents.html

PART B: SUMMARIZE PRINCIPLES IN YOUR OWN WORDS AND WITH SKETCHES

Learn about the Principle of Stratigraphy and Principles of Relative Dating, which sometimes are called "laws." Find the principles from your reading above. In YOUR OWN WORDS, fill in the chart below and on the next page. Some of the information is found by clicking on terms with links. Two principles are given as examples of how to complete the table.

You can read about the first three principles in <u>Fossils, Rocks, and Time</u> http://pubs.usgs.gov/gip/fossils/contents.html by searching through the site yourself

PRINCIPLES OF STRATIGRAPHY	DESCRIPTION AND LABELED SKETCH
Principle of Superposition	
Principle of Original Horizontality	
Principle of Fossil Succession	
Principle of Inclusions	In this cross-section Rock A is a sedimentary rock and Rock B is an intrusive igneous rock. Rock A contains pieces (sediments) derived from Rock B, therefore, Rock A must be younger than Rock B. 
Principle of Cross-Cutting Relations for Faults	 In this cross-section Rocks A, B, C and D are layers of sedimentary rock which formed as continuous layers but are now offset along the fault, therefore, the fault must be younger than all the layers.

PRINCIPLES OF RELATIVE AGE DATING from Geologic Time and other sources	DESCRIPTION AND LABELED SKETCH
Principle of Cross-cutting Relations **http://pubs.usgs.gov/gip/fossils/laws.html**	
Correlation **http://pubs.usgs.gov/gip/geotime/correlation.html** **http://pubs.usgs.gov/gip/geotime/section.html**	
Unconformity **(very important feature as an unconformity may represent** **more time that is missing, than is present in the rocks.) Take a look at this animation.** **http://www.classzone.com/books/earth_science/** **terc/content/visualizations/es2902/es2902page01.** **cfm?chapter_no=visualization**	
How scientists use radiometric age dating of igneous rock to "bracket" ages of sedimentary rock **http://pubs.usgs.gov/gip/geotime/chart.html**	

COMPARING YOUR OBSERVATIONS AND INFERENCES AND SCIENTISTS' IDEAS

How did your observations and inferences that you completed in Initial Ideas compare with the Scientists' Ideas regarding the Principles of Stratigraphy? Please write and explain any similarities your ideas have with scientists' ideas.

Please write and explain how your ideas differed.

GEOPUZZLE PRACTICE! RELATIVE AGE DATING PRINCIPLES

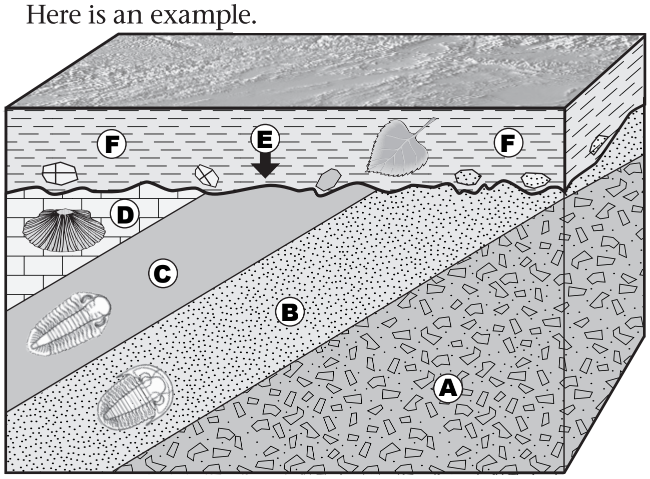
Are you good at puzzles – sudoku, crosswords, hangman? Let's try Earth's versions! The main idea is to figure out the order of geologic events that took place. The diagrams represent a cut out side view of Earth called geologic cross-sections. A cross-section is a slice into Earth viewed from the side, like looking at a beach cliff (as compared to an eagle's view which looks down from above). Geologic cross-sections show a representation of what an area of Earth looks like using an outcrop scale. Represented are rock layers, buried surfaces of erosion or periods of non-deposition (gaps in the geologic record = unconformity), igneous intrusions, faults, etc. Again, the object of the geopuzzle is (using logic) to list in order from oldest to youngest the events that took place. Then you justify your inference by writing down the principle of stratigraphy/ relative age dating that you used.

TABLE 1 COMMON GEOLOGIC EVENTS

EVENT	WHAT HAPPENED
Deposition	Sediments accumulate in layers and are buried by more sediments and eventually get deep enough to become sedimentary rock
Erosion	Wearing away of the land surface by the removal (by stream, glaciers, etc.) of sediments
Faulting	Displacement of the crust along a fracture due to the continuous application of stress leading to the buildup of strain energy and then the sudden release of that energy causing an earthquake.
Intrusion	Magma (molten rock) rising up into preexisting rock of the crust and subsequently cooling to form intrusive-igneous rock.
Lava Flow	Magma rises from Earth's interior and flows, as lava, from a volcanic vent.
Uplift	Upward movement of Earth's surface commonly associated with mountain building processes.
Tilting	Deformation (folding) of horizontal layers of rock also associated with mountain building.
Climate Change	Warming: Average global temperature increases.
	Cooling: Average global temperature decreases.
Glacial Advance	Glacier increases in size and forward movement of the glacier's toe (terminus) occurs. Glacial movement causes erosion and glacial striations (scratch marks) are evidence of motion and erosion.
Glacial Retreat	Glacier decreases in size and the glacier's toe moves back toward the glacier's point of origin. As retreat occurs ice is melting and depositing sediments to form a glacial till, a very poorly sorted and unlayered deposit of sediments
Crustal Depression	Weight of added Earth materials pushes the crust down into Earth's interior, the mantle.
Isostatic Rebound	When the weight of the added Earth materials is removed the crust rises back to its former position.

GEOPUZZLE 1

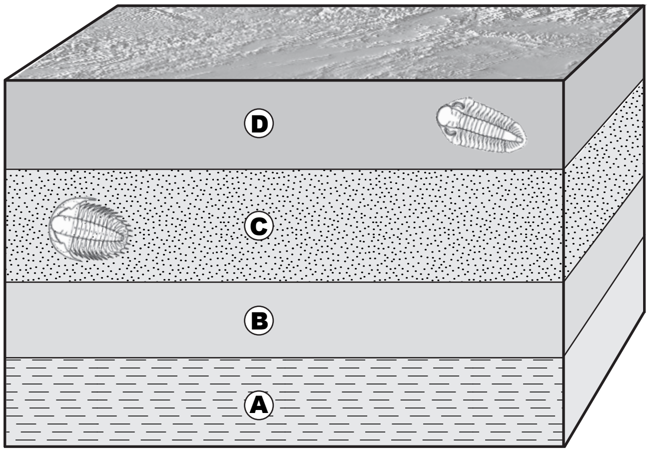
Here is an example.



		EVENT - PRINCIPLE
Youngest	F	Deposition – Layer F contains Inclusions of layers B,C,D
	E	Tilting, (uplift), erosion of layers A-D - Unconformity (buried surface of erosion)
	D	Deposition - Superposition, original horizontality
	C	Deposition - Superposition, original horizontality
	B	Deposition - Superposition, original horizontality
Oldest	A	Deposition - Superposition, original horizontality

GEOPUZZLE 2

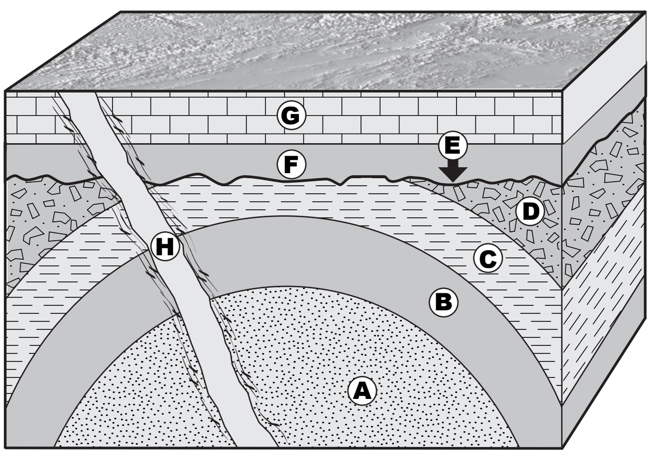
Too easy?



	EVENT - PRINCIPLE
Youngest	
Oldest	

GEOPUZZLE 3

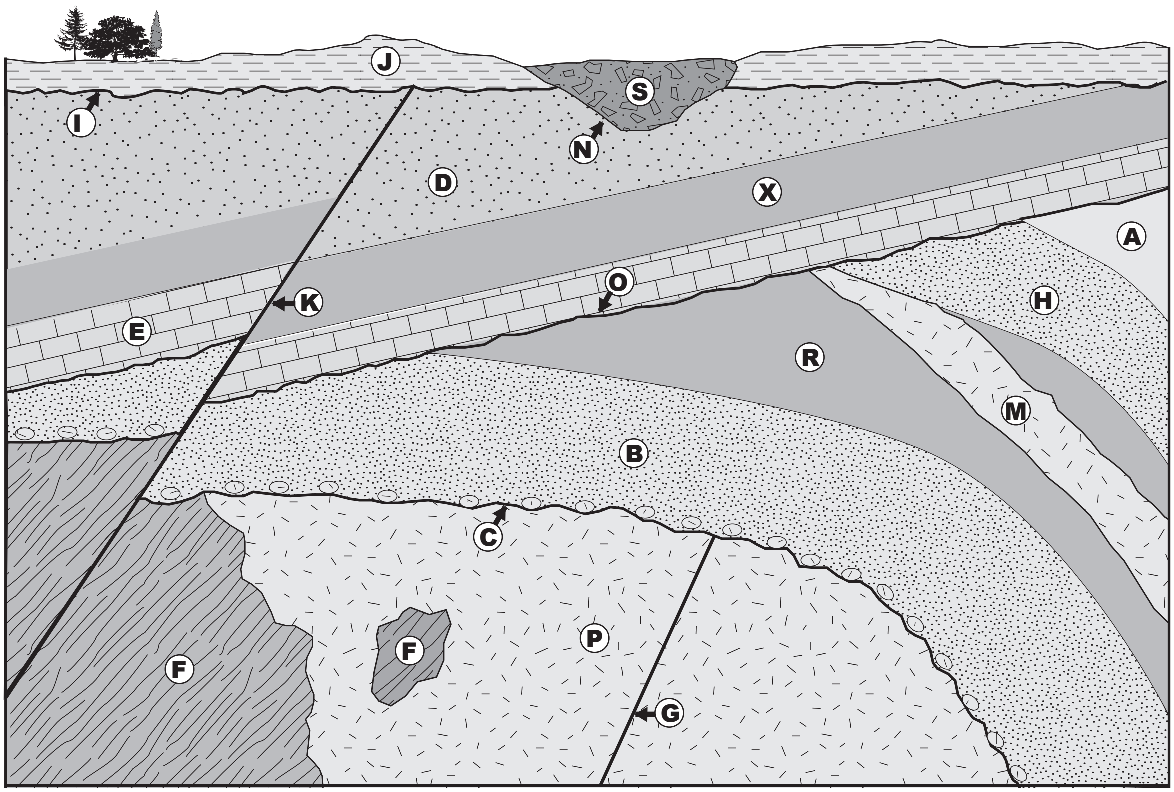
More challenging!



	EVENT - PRINCIPLE
Youngest	
Oldest	

GEOPUZZLE 4

See if you can figure this one out! See key to rock types on next page.



Key to Geopuzzle 4 on next page

	EVENT - PRINCIPLE
	YOUNGEST

	EVENT - PRINCIPLE

	EVENT - PRINCIPLE
	OLDEST

KEY FOR IDENTIFYING "LETTERS" ON GEOPUZZLE 4			
Sedimentary Rock Layers	A, B, D, E, H, J, R, S, X	Intrusive-Igneous Rocks	M, P
		Faults	G, K
Metamorphic Rocks	F	Unconformities	C, I, N, O

SUMMARIZING QUESTION

REVISIT STEP 3 FROM INITIAL IDEAS
RELATIVE AGE DATING FOR THE ROCK UNITS SHOWN IN THE PHOTOGRAPH

Apply what you have learned about the Principles of Stratigraphy. Write down the chronologic order of events that took place in order to form the sequence that you see in the beach cliff photograph from the initial ideas.

Did your ideas about chronologic order change from your Initial Ideas? Explain how your ideas changed or how they did not change.

SUMMARY

Layers of rocks record the history that Earth has changed through time. Learning to read the story recorded in the rocks reveals the history. To understand the history, you develop background knowledge needed to understand the story that takes PRACTICE. To unravel the details of the story you need to know and understand things like:

- If conditions on Earth had remained the same over time, the layers would all be the same. We see that Earth preserves abundant evidence for change over time, when we know what to look for.
- How different rock types form and what the rock type reveals about the environment in which they formed: the main rock types are called sedimentary, igneous and metamorphic rocks. We observe how and where rocks form today and infer how they formed in the past.
- The relationship between the rock units will tell if the rocks formed in a continuous sequence or if interruptions or disruptions took place during or after the time that the rocks formed. The geologic history of a region can be unraveled by using Principles of Stratigraphy and logic. Principles include: superposition, original horizontality, cross cutting relationships, inclusions, correlation, fossil succession.
- Biology skills, how to recognize the preserved remains of ancient life (fossils). Since organisms require specific conditions in order to live, we can use the presence of fossils to say something about the environment of deposition of the sediment that lithified (hardened by compaction and/or cementation) to form the rocks.
- Certain fossils are used in fossil succession as time markers and to correlate sedimentary layers. Paleontologists recognize
- Earth is a dynamic place where mountains are built and are worn down. In Cycle 3 you are learning about evidence for plate boundaries and the features that are associated with these dynamic places.
- The rock record preserved is not complete for any one place on Earth. Erosion and time periods of non-deposition in different areas of our planet create gaps in the rock record. Worldwide correlation and extensive collaboration among scientists has established a geologic history of Earth.
- With new technology and new scientific discoveries, more information results in refinement or changes in the way things are explained.

For further investigation, other online resources:
University of California Museum of Paleontology (at UCBerkeley)
The development of the Geologic Time Scale:
http://www.ucmp.berkeley.edu/exhibit/histgeoscale.html
A Geologic Time tour of Earth History: Lots of pictures of fossils through time.
http://www.ucmp.berkeley.edu/exhibits/geologictime.php